

A.K. Thompson

FRUIT AND VEGETABLES

Harvesting, Handling and Storage

Third Edition • Volume I • Introduction & Fruit



WILEY Blackwell

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Fruit and Vegetables

To

*Elara, Maya, Ciaran, Caitlin and Cameron
to whom I owe much more than they will ever know*

Fruit and Vegetables

Harvesting, Handling and Storage

Third Edition

Volume 1
Introduction and Fruit

A.K. Thompson

WILEY Blackwell

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About the Author



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Preface

The awareness of the importance of plants in the human diet has developed into detailed scientific study. The role of plants in medicine seems to have always been known and even today searches are being constantly made to find chemicals in plants that can be used to prevent or cure disease in modern medicine. A vast range of plant species have been eaten throughout the history of mankind. Presumably, initially human beings started using plants and their products from gathering them in the wild and eventually finding ways of cultivating them. This is the history of the development of agriculture. Even now people are still collecting plants for food from the wild in tandem with the development of breeding new cultivars of these crops and improved ways of cultivating them. Keller and Tukuitonga (2007) stated that 'Low fruit and vegetable intake was identified as an important risk factor for chronic diseases in the WHO World Health Report 2002. Overall, it is estimated that up to 2.7 million lives could potentially be saved each year if fruit and vegetable consumption was sufficiently increased.' The nutritional properties of vegetables and fruit have been known for centuries. In the 18th century a French pharmacist Antoine-Augustin Parmentier demonstrated, for several years by his own diet, that all the nutrients required to sustain a healthy life were found in potatoes (Block 2008). The quality of the plant material in terms of nutrition and the maintenance of that quality and reducing their physical losses from harvest to reaching the consumer have been the subject of a vast number of research projects. Changes that can occur may be due to infections by microorganisms or by the physiological processes that continue in vegetables and fruit since they are still living organisms with life processes that are severed from their sources of renewal and sustenance.

The technology involved in getting fresh produce from the field to the consumer is enormously complicated because many of the crops are highly perishable and variable. This variability militates against simple solutions. The fresh produce trade would prefer not to be involved with this variation and complexity. They would prefer to be able to look up their particular crop on a chart, which will say it should be harvested,

packaged and stored in a certain way. Information in this form is readily available but will rarely give the best results in terms of preserving the quality of the crop. The objective of this book is the same as the two previous editions, which is to provide a range of postharvest options from which the produce technologist can select. Additionally it puts into context our current state of knowledge on postharvest science and technology and thus identifies areas where research is needed.

In order to provide a context for understanding the differences in research results and interpreting them some background information has been supplied on each fruit or vegetable. Also some taxonomy is included because of the difficulties in knowing exactly which crop the researchers have referred to. This may well help in determining the differences in results. The information in this book and the way that it is presented is therefore largely what is perceived to be required by the industry. Also there is increasing pressure for universities to provide graduates who are more relevant to the needs of industry, and most students of postharvest science and technology will eventually work in the industry or in some way be associated with it; so the book will also serve their needs. The parts on tropical root crops have relied heavily on two of the publications of Daisy Kay. From 1970 Daisy and I worked together at the Tropical Products Institute in London. TPI subsequently became the Tropical Development and Research Institute. The 1973 edition of her *Root Crops: Crop and Product Digest* was so well received that it was decided in the Institute to produce a second edition. Because Daisy had died and because of research and overseas consultancy work no one suitably qualified in the Institute had sufficient time to revise Daisy's work and so Graham Gooding was employed and with the co-operation of members of the Institute produced the excellent second edition in 1987. C.W. Wardlaw and his associates working in Trinidad at what eventually became the University of the West Indies is also a major source of information. Wardlaw was the Head of the Botany Department at Manchester University in 1960 and 1961 when I worked there

as a lowly gardener in their Botanic Gardens. I subsequently was responsible for sorting out Wardlaw's notes and data and those of his predecessor S.C. Harland in Trinidad when the library at the University was relocated in 1969 while I was working there as a Research Fellow. Another major source is the work of Dr J.M. Lutz and Dr R.E. Hardenburg published in the United States Department of Agriculture Bulletin 66, which I was pleased to see has been revised and is constantly updated on the Internet by some of the most experienced postharvest technologists.

The work of this book is based on a selective review of the literature and my experiences since I was first formally involved in postharvest technology in 1967. Since that time postharvest technology has taken me all over the world doing short consultancies and long-term assignments, of up to 3 years, meeting particular challenges in research, training and development of the fruit and vegetable industry. Although much of my time has been spent as an academic and

government or United Nations adviser, I have always worked closely with the horticultural industry. The information in this book and the way that it is presented is therefore largely in a form that I perceive to be required by the industry.

In this third edition I have brought the information up-to-date and widened its scope by including some fruit and vegetables that were not included in the first two editions. Comments have been made on the lack of information and discussion on the benefits of consumption of fruit and vegetables and levels of various nutrients they may contain and how these may change postharvest. So some nutritional data has been included and I am indebted to the USDA nutrient database for much of this information. Also I have included more details on taxonomy since it has been pointed out that there is often confusion as to which crop is being referred to. I have also included a little on the origin and history of the crops for which I have relied to a considerable degree on the excellent publications of Julia Morton and J.W. Purseglove.

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1

Preharvest factors on postharvest life

The quality of a crop at harvest can have a major effect on its postharvest life. There are numerous factors involved and these factors frequently interact giving complex interrelationships. In tree crops, fruit produced on the same tree and harvested at the same time may behave differently during marketing or when stored. The issues that influence produce quality include obvious things, such as harvest maturity and cultivar or variety, but also the climate and soil in which it was grown, chemicals which have been applied to the crop, and its water status. Many of these factors can also interact with time such as when fertilizers or irrigation is applied or the weather conditions near to the time of harvest.

An equation was proposed (David Johnson 1994, personal communication) to predict the probability of low temperature breakdown in apples in storage where variance accounted for 56%. This equation was based on preharvest factors such as temperature, rainfall and nutrient level in the leaves and fruit of the trees as follows:

$$8.2 + 4.5 T_{\max} [J] - 2.9 T_{\max} [A - S] + 0.11 \text{ rain} [A + S] - 16.4 \text{ leaf N} - 3.9 \text{ fruit P}$$

where:

$T_{\max} [J]$ = mean daily maximum temperature in June

$T_{\max} [A - S]$ = difference in mean daily maximum temperature in August and September

$\text{rain} [A + S]$ = total rainfall in August and September

leaf N = level of nitrogen in the leaves

fruit P = level of phosphorous in the fruit.

Nutrients

The soil type and its fertility affect the chemical composition of a crop. Excess or deficiency of certain elements from the crop can affect its quality and its postharvest life. Many storage disorders of apples are associated with an imbalance of chemicals within the fruit at harvest (Table 1).

The relation between the mineral composition of fruits and their quality and behaviour during storage is not always predictable (Table 2) but in some cases the mineral content of fruits can be used to predict storage quality. For good storage quality of Cox's Orange Pippin apples it was found that they required the following composition (on a dry matter basis): 50–70% N, 11% minimum P, 130–160% K, 5% Mg and 5% Ca for storage until December at 3.5 °C or 4.5% Ca with minimum storage in 2% O₂ and <1% CO₂ at 4 °C until March (Sharples 1980).

Table 1 Storage disorders and other storage characteristics of Cox's Orange Pippin apples in relation to their mineral content (source: adapted from Rowe 1980)

Disorder	Composition in mg 100 g ⁻¹				
	N	P	Ca	Mg	K/Ca
Bitter pit	–	–	<4.5	>5	>30
Breakdown	–	<11	<5	–	>30
Lenticel blotch pit	–	–	<3.1	–	–
Loss of firmness	>80	<11	<5	–	–
Loss of texture	–	<12	–	–	–

The physiological disorder that results in the production of colourless fruit in strawberries is called albinism. The fruit, which were suffering from this physiological disorder, were also found to be softer. The ratio of potassium:calcium and nitrogen:calcium was found to be greater in fruit suffering from albinism than in red fruit (Lieten and Marcelle 1993). Albinism was associated with the cultivar Elsanta and some American cultivars, and the recommendation for control was either to grow only resistant cultivars or decrease the application of nitrogen and potassium fertilizers (Lieten and Marcelle 1993).

The application of fertilizers to crops has been shown to influence their postharvest respiration rate. This has been reported for a variety of fertilizers on several crops including potassium on tomatoes, nitrogen on oranges and organic fertilizers on mangoes. An example of this is that an imbalance of fertilizers can result in the physiological disorder of watermelon called blossom-end rot (Cirulli and Ciccarese 1981). However, care must be taken in interpreting experimental results since the application of fertilizers may simply be correcting nutrient deficiencies in

the soil that may be having detrimental effects of the physiology of the crop.

Nitrogen

Generally crops that contain high levels of nitrogen typically have poorer keeping qualities than those with lower levels. Results on the effects of nitrogen fertilizer on the storage life have been variable. In shallots the highest incidence of sprouting was found in the treatment combination of 150 kg N ha⁻¹, 50% top fall harvest and non-cured bulbs which accounted for 16.73% sprouting, while the least was observed from zero N, 75% top fall harvest and cured bulbs which was 2.37% at the end of 3 months of storage (Woldetsadik and Workneh 2010). Bhalekar *et al.* (1987) also observed that sprouting of onions was increased with increasing nitrogen levels from 0 to 150 kg N ha⁻¹. Dankhar and Singh (1991) also reported that high dose of nitrogen produced thick-necked onion bulbs that increased sprouting in storage while Ystaas (1980) showed that the application of nitrogen fertilizer to pear trees did not affect the soluble solids content, firmness, ground colour or quality of the fruit. Kodithuwakku and Kirthisinghe (2009) applied different levels of urea fertilizer to growing cauliflowers and found no significant difference in the postharvest quality of cauliflower curds. However, they found that applying 50% of the recommended N fertilizer resulted in an extension in their postharvest life of 6 days longer than other treatments in storage in ambient conditions. Anonymous (2010) reported that limiting nitrogen fertilizer resulted in improved shape, size and storability of swedes (*Brassica napus* var. *napobrassica*).

Application of N fertilizer can affect postharvest quality. Link (1980) showed that high rates of N

Table 2 Summary of the most consistent significant correlations between mineral composition (fruits and leaves) and storage attributes in a 3-year survey (1967, 1968 and 1969) of Cox's Orange Pippin commercial orchards (source: adapted from Sharples 1980)

	Positive correlation years	Negative correlation years
Fruit firmness	Fruit P (68, 69)	–
<i>Gloeosporium</i> rot susceptibility	Fruit K/Ca: Mg Ca (67, 68, 69)	Fruit Ca (67, 68, 69)
Bitter pit	Fruit K/Ca: Mg Ca (67, 68, 69)	(67, 68, 69)
Senescent breakdown	–	Fruit Ca (67, 68, 69)
Core flush	Leaf K (67, 69) (August)	Leaf N (68, 69) (July)
Low temperature breakdown	Fruitlet	Ca P (67, 68, 69) (July)

fertilizer to apple trees could adversely affect the flavour of the fruit. Comis (1989) reported that too much soil nitrogen could reduce the vitamin C content of Swiss chard. Rogozinska and Pinska (1991) found that loss of tuber weight during storage increased with increasing fertilizer rate but loss of starch was high only at high N rates (200 kg N ha^{-1}). They also found a negative effect on the organoleptic value of tubers after 200 kg N ha^{-1} , especially after 6 months of storage. Potatoes grown with high levels of N had lower amounts of free sugars at all times (Roe *et al.* 1990). High N levels delayed tuber formation resulting in more immature tubers when harvested at the same time compared with tubers grown with lower N levels (Bodin 1988). Admiraal (1988) found that tuber density was less within those that had been grown in 150 kg N ha^{-1} applied 4 weeks after harvest and after 3 months of storage at 10°C compared with those grown without N fertilizer. Kolbe *et al.* (1995) found that at harvest, the glucose and fructose contents in tubers were lower for those that had been grown with high rates of N fertilizer compared to low rates or absence of fertilizers, but throughout storage, reducing sugar accumulation increased, sucrose reduction decreased and ascorbic acid content increased. N decreased reducing and non-reducing sugar content after storage for 3 months at 10 or 15.5°C (Badshah *et al.* 1990). During storage of potatoes at 4°C and 90% r.h. there was an increase in water loss of 54% as a result of N fertilization (Kolbe *et al.* 1995). Woldetsadik and Workneh (2010) found that with a basic dressing of $92 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$ increasing N levels (0, 50, 75 or 100 kg ha^{-1}) showed proportional increase in the shallot bulb pungency levels, but the dry matter, TSS, total sugars and reducing sugars were not significantly affected either at harvest or during storage. However, there were increments in the percentage bulb rotting, sprouting and weight loss with increased N levels. Since nitrogen fertilizer can affect quality it may be summarized that they could affect their susceptibility to handling damage. However, increasing levels of N fertilizer application did not affect the susceptibility of potato tubers to mechanical damage (Divis and Sterba 1997) although Kolbe *et al.* (1995) found that high N resulted in an increase in pectic substances and lower cellulose content.

Application of nitrogen fertilizer to pome fruits and stone fruits has been shown to increase their

susceptibility to physiological disorders and decrease fruit colour (Shear and Faust 1980). High nitrogen increased the susceptibility of Braeburn apples to flesh and core browning during storage (Rabus and Streif 2000). In fertilizer trials on avocados Köhne (1992) showed that the application of nitrogen could reduce the percentage of "clean" fruit, but where it was combined with magnesium and potassium there was no effect. In a field experiment in the Netherlands there were variable results to field application of nitrogen fertilizer, but during storage at 12°C and 90% r.h. for 10 days after the first harvest, nitrogen had no effect on the yellowing of small Brussels sprouts. However, the application of 31 kg N ha^{-1} as calcium nitrate resulted in increased yellowing of large sprouts. At the second harvest, no effect of nitrogen was observed (Everaarts 2000). Nitrogen fertilizer has also been shown to affect susceptibility to disease. Bunches of Italia grapes from vines treated with 35% nitrogen as urea and 65% as $\text{Ca}(\text{NO}_3)_2$ through fertigation had less water loss and less decay after 56 days of storage at $2\text{--}4^\circ\text{C}$ and 90–95% r.h. than the bunches from treatments that had higher levels of nitrogen (Choudhury *et al.* 1999). *Alternaria alternata*, *Cladosporium herbarum*, *Penicillium* sp., *Rhizopus* spp. and *Aspergillus niger* caused storage decay in those trials. Conversely, Pertot and Perin (1999) showed that excessive nitrogen fertilization significantly increased the incidence of rot in kiwifruit during subsequent cold storage, both in the year of application and in the following year. Woldetsadik and Workneh (2010) found that there was increased rotting of shallots, sprouting and weight loss with increased N levels. Translucence in pineapple has been related to high nitrogen as well as high radiation, temperatures and rainfall during growth (Paull and Reyes 1996). Srikul and Turner (1995) reported that high N applications reduced green life of banana fruit.

Phosphorus

In the limited published work, ensuring sufficient phosphorous in the crop generally had beneficial postharvest effects. For example in cucumber fruits phosphorus nutrition can alter their postharvest physiology by affecting membrane lipid chemistry, membrane integrity and respiratory metabolism. Cucumbers were grown in a greenhouse under low

and high phosphorus fertilizer regimes by Knowles *et al.* (2001). Tissue phosphorus concentration of the low phosphorus fruits was 45% of that of fruits from high phosphorus plants. The respiration rate of low phosphorus fruits was 21% higher than that of high phosphorus fruits during 16 days of storage at 23 °C, and the low phosphorus fruits began the climacteric rise about 40 h after harvest, reached a maximum at 72 h and declined to pre-climacteric levels by 90 h. The difference in respiration rate between low and high phosphorus fruits was as high as 57% during the climacteric. The respiratory climacteric was different to the low phosphorus fruits and was not associated with an increase in fruit ethylene concentration or ripening. Kolbe *et al.* (1995) found that increasing the levels of phosphate fertilizer during the growth of potatoes resulted in decreased weight losses during storage at 4 °C and 90% r.h. for 6 months. Phosphorus levels in tubers were reported to be 0.093% by Banks and Greenwood (1959). Singh *et al.* (1998) found that the application of 100 kg ha⁻¹ of phosphorus minimized the weight loss, sprouting and rotting in onions during 160 days of storage compared to lesser applications.

Potassium

Generally application of potassium fertilizers had beneficial postharvest effects, but there was some evidence of increases in crop acidity, and application of high rates could have negative effects. Cirulli and Ciccarese (1981) found that the application of potassium fertilizer to watermelons was shown to decrease the respiration rate of the fruit after harvest. In tomato fruits dry matter and soluble solids content increased as potassium rate increased, but there were no significant differences in TA at different potassium rates (Chiesa *et al.* 1998). Spraying Shamouti orange trees with a potassium fertilizer increased potassium concentration in the fruit and reduced the incidence of the physiological fruit storage disorder called superficial rind pitting (Tamim *et al.* 2000). Hofman and Smith (1993) found that the application of potassium to citrus trees could affect the shape of their fruits and increase their acidity, although this effect was not observed when potassium was applied to banana plants. High potassium generally increased acidity in strawberries, but this effect varied between cultivars (Lacroix and Carmentran 2001). A soil drench

with potassium chlorate extend the fruiting season of longan (Subhadrabandhu and Yapwattanaphun 2001, Jiang *et al.* 2002). Rogozinska and Pinska (1991) found that 320 kg K₂O ha⁻¹ had a negative effect on the organoleptic value of potato tubers, especially after 6 months of storage.

There is compelling evidence of a significant reduction in susceptibility of potato tubers to damage with increasing the rate of application of potassium fertilizer. However, the effect is not large and was primarily observed for the potassium deficient range of concentrations (McGarry *et al.* 1996). In a field experiment by Singh *et al.* (1996) tubers were given 0–180 kg K₂O ha⁻¹ and when tubers were stored for 14 weeks losses and sprouting were the lowest where 180 kg K₂O had been applied. In contrast Sharma and Ezekiel (1993) found that sprout weight was increased with K₂O application after 60 days of storage but tuber weight loss and sprouting were not affected. They also found that dry matter, ascorbic acid and total sugar content of tubers increased with application of K₂O. Panique *et al.* (1997) reported a reduction in specific gravity with increasing applied potassium in most of the site-years, and a significant decrease in hollow heart with increasing rate of potassium fertilizer application was observed in 4 of 11 site-years. They also reported that the incidence of *Rhizoctonia solani* was generally not affected by potassium rate, but there was a tendency in some site-years for a higher disease incidence when KCl was used instead of K₂SO₄ (Panique *et al.* 1997). Kolbe *et al.* (1995) found that at harvest, the glucose and fructose contents in tubers were reduced by high potassium fertilizer rates compared to low or absence of fertilizers, but throughout storage, reducing sugar accumulation increased, sucrose reduction decreased and ascorbic acid content increased. Badshah *et al.* (1990) found that potassium fertilizer had a negative effect on tuber quality only at rates above 240 kg ha⁻¹.

Calcium

The physiological disorder of stored apples called bitter pit (Figure 1) is principally associated with calcium deficiency during the period of fruit growth and may be detectable at harvest or sometimes only after protracted periods of storage (Atkinson *et al.* 1980). The incidence and severity of bitter pit are influenced also by the dynamic balance of minerals

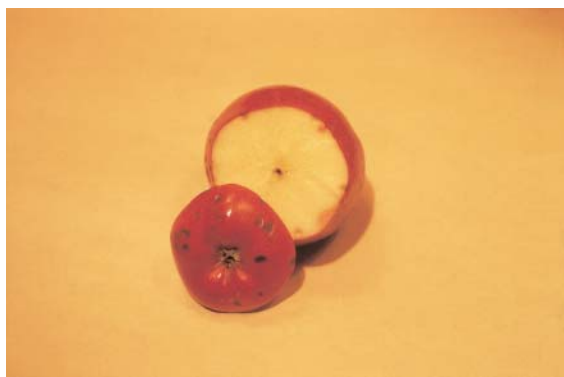


Figure 1 Bitter pit on a Red Delicious apple in Turkey. See colour plate section.

in different parts of the fruit as well as the storage temperature and levels of O_2 and CO_2 in the store atmosphere (Sharples and Johnson 1987). de Freitas *et al.* (2010) observed in Granny Smith that calcium accumulation into storage organelles and calcium binding to the cell wall represent important contributors to bitter pit development in apples. They found an increase in the expression of genes encoding four pectin methylesterases, a greater degree of pectin de-esterification and therefore more calcium binding sites in the cell wall. They also reported a higher fraction of the total cortical tissue calcium content that was bound to the cell wall in pitted fruit compared with non-pitted fruit. Cells of the outer cortical tissue of pitted fruit consistently had higher membrane permeability than outer cortical cells of non-pitted fruit. Low calcium levels in fruit were also shown to increase the susceptibility of Braeburn apples to flesh and core browning (Rabus and Streif 2000). Calcium has also been associated with postharvest factors in other fruit for example in tomatoes blossom-end rot has been associated with low calcium and high potassium fertilizers (Ho *et al.* 1993). In papayas, low mesocarp calcium concentrations have been linked with fruit softening (Qiu *et al.* 1995). In a 3-year study of potatoes by Clough (1994) on fine sandy loam soil calcium sulphate was applied before planting and calcium nitrate as a side dressing. After 4 months of storage at 7 °C, severity and percentage of tubers with internal brown spot were reduced by calcium application either before planting or as a side dressing.

The treatment of tomato plants with a foliar spray of calcium or a postharvest dip effectively increased cell

wall calcium, which is associated with fruit texture (Wills and Tirmazi 1979). Niitaka pears from trees that had been supplied with liquid calcium fertilizer were firmer after storage than fruit from trees that had not been treated (Moon *et al.* 2000). Blueberry plants that had calcium sulphate applied to them at 0.06 kg m⁻² had 10% more calcium content within the cell wall at harvest the following year and less softening and weight loss during storage at 2 °C for 23 days compared to those that had not had the treatment (Angeletti *et al.* 2010). Kiwifruit vines of the cultivar Hayward were sprayed with liquid calcium (Nutrical) at 9.33 L ha⁻¹ on 3 days between fruit set and 10 days before harvest. During controlled atmosphere storage kiwifruits from vines that had been sprayed with 9.33 L ha⁻¹ of Nutrical were firmer and of better quality than fruits that had not been sprayed (Basiouny and Basiouny 2000). Ortiz *et al.* (2012) found that spraying Fuji Kiku-8 apple trees with calcium improved the preservation of the middle lamella in fruit cells by higher contents of ionically bound pectins leading to higher fruit firmness levels at commercial harvest. Matrix glycan breakdown was also delayed in response to calcium treatment. Calcium applications partially suppressed pectinmethylesterase, pectate lyase, β -galactosidase, α -L-arabinofuranosidase and β -xylosidase activities, without any apparent relationship with ethylene production rate.

Besada *et al.* (2008) reported that calcium nitrate applied to fruit of the persimmon cultivar Rojo Brillante prior to harvesting combined with 1-MCP applied postharvest delayed the symptoms of chilling injury and extended their storage at 1 °C for almost 3 months. Lower chilling injury occurred in kiwifruit during storage at 0 °C for up to 42 weeks from vines that had been sprayed with 1% calcium chloride four times during fruit development. Low temperature breakdown incidence was assessed after 5 days at 20 °C subsequent to storage (Gerasopoulos and Drogoudi 2005). Hartman *et al.* (2000) found that calcium chloride in the irrigation water resulted in mushrooms that were more resistant to the negative effects of excessive handling or bruising.

Fruit weight loss was reduced following liquid calcium fertilizer treatment, but there was no effect on soluble solids contents (Moon *et al.* 2000). Calcium sulphate applied to sapodilla trees at up to 4 kg per tree once every week for the 6 weeks prior to harvest

improved the appearance of fruit, pulp colour, taste, firmness, aroma and texture after storage in ambient conditions (Lakshmana and Reddy 1995). High calcium fertilizer levels reduced acidity of strawberries, but contributed to the loss of visual fruit quality after harvest (Lacroix and Carmentran 2001). Spraying guava trees with 1% calcium nitrate resulted in the lowest mean loss in weight, respiration rate and acidity, highest TSS and ascorbic acid and maintained the firmness of fruits during storage longer than the fruit that had not been sprayed or those sprayed with other calcium nitrate concentrations. Spraying clusters of both longkong and langsat fruit with 5% calcium chloride 10 and 11 weeks after fruit set reduced fruit drop and increased fruit firmness, TSS content and the ratio of TSS to TA (Rattanapong *et al.* 1995). Potato tuber quality during storage for 6 months at 25 °C was greatly increased in tubers that had been grown in nutrient solution containing 972 mg Ca L⁻¹ compared to those with zero or lower calcium concentrations in the solution (Paiva *et al.* 1997). Addition of calcium chloride to irrigation water increased calcium content and improved quality of mushrooms independent of inherent calcium content (Varoquaux *et al.* 1999). Hartman *et al.* (2000) also showed that significant improvements in mushroom quality resulted from addition of 0.3% calcium chloride to the irrigation water but the treatment slightly reduced crop yield. The effect of the calcium chloride was to improve initial whiteness at harvest and reduce postharvest browning compared to those not treated. When calcium chloride and sodium selenite were both added, the positive effects remained and all these negative trends were reversed.

Guava trees that had been sprayed with 1% calcium nitrate had reduced incidence of postharvest disease caused by *Pestalotia psidii* after 9 days of storage compared to fruit that had not been sprayed (Singh and Singh 1999). Chervin *et al.* (2009) reported that spraying vines with a 16% ethanol solution containing 1% calcium chloride reduced grey mould in the grape cultivar Chasselas from 15% in controls to 5% development during 6 weeks of cold storage. This was on fruit picked at a late harvest date and the treatment did not result in significant changes in fruit quality assessed by sensory analysis of healthy berries. In a 3-year study of the apple cultivar Idared Holb *et al.* (2012) found that integration of preharvest calcium sprays and CA storage

minimized fruit injury/infection particularly brown rot incidence caused by *Monilinia fructigena* during long-term storage.

Magnesium

In potatoes the influence of magnesium and calcium in the cell wall and middle lamella on resistance to postharvest diseases was studied in two genotypes with large differences in their levels of resistance. Increased content of magnesium, especially in the periderm and cortex, clearly improved resistance to *Phoma exigua* var. *foveata* but not to *Fusarium solani* var. *coeruleum*. The effect of magnesium was greater than that of calcium and the results indicated that the ratio of Mg : Ca might be of importance for resistance to gangrene. The pectin-bound Mg that gives a firmer cell wall and middle lamella than the pectin-bound calcium can explain this effect (Olsson 1988).

Micronutrients

In India Shashirekha and Narasimham (1990) found that dipping potato seed tubers in aqueous solutions of trace element salts decreased both sprouting and microbial spoilage during storage in ambient conditions.

Soil acidity

Soil acidity can affect not only the yield but also the quality of a crop, which in turn could affect postharvest attributes. However, the literature does not provide confirmation of this assumption. For example Kihurani *et al.* (2008) showed that growing sweet potato in soil at the different pH levels of 4.6, 5.8 and 6.1 did not significantly influence postharvest pathological deterioration of the roots caused by *Rhizopus oryzae* and *Botryodiplodia theobromae*.

Organic production

The market for organically produced food is increasing. There is conflicting information on the effects of organic production of fruit and vegetables on their postharvest characteristics. Organic production has been shown to result in crops having higher levels of postharvest diseases. Massignan *et al.* (1999) grew

Italia grapes both conventionally and organically and after storage at 0 °C and 90–95% r.h. for 30 days they found that organic grapes were more prone to storage decay than those grown conventionally. In another case there was evidence that organic production reduced disease level. In samples from organically cultivated Bintje and Ukama potato tubers the gangrene disease (*Phoma foveata*) levels were lower compared with conventionally cultivated ones. However, there was no such difference in King Edward and Ulama tested 4 months later. The dry rot (*Fusarium solani* var. *coeruleum*) levels were generally lower in organically cultivated potatoes compared with tubers from the conventional system (Povolny 1995).

Producing crops organically can have other effects. Although harvested on the same day, conventionally produced kiwifruits were generally more mature, as indicated by TSS concentrations, but their average firmness did not differ significantly for those produced organically. Despite the differences in maturity, whole fruit softening during storage at 0 °C did not differ significantly with production system. However, organically grown fruits nearly always developed less soft patches on the fruit surface than conventionally grown fruits (Benge *et al.* 2000). The effect of organic compost fertilization on the storage of Baba lettuce was evaluated by Santos *et al.* (2001). The organic compost was applied at 0, 22.8, 45.6, 68.4 and 91.2 tonnes per hectare on a dry matter basis, with and without mineral fertilizer. They reported that during storage at 4 °C lettuce grown in increasing rates of organic compost had reduced levels of fresh weight loss by up to 7%. The chlorophyll content decreased during storage when plants were grown with 45.6 and 91.2 tonnes per hectare of organic compost with mineral fertilizers compared to the other levels. The fertilization with organic compost and mineral fertilizer altogether resulted in plants with early senescence during cold storage.

In a survey in Japan about the fruit quality of Philippine bananas from non-chemical production, the problems highlighted all related to management practices and none to the effects of organic production on postharvest aspects (Alvindia *et al.* 2000). However, in Britain Nyanjage *et al.* (2000) found that imported organically grown Robusta bananas ripened faster at 22–25 °C than non-organically grown bananas as measured by peel colour change, but ripe fruit had

similar TSS levels from both production systems. The peel of non-organic fruits had higher nitrogen and lower phosphorus contents than organic fruits. Differences in mineral content between the pulp of organic and non-organic fruits were much lower than those between the pulp and the peel.

Light

Fruits on the parts of trees that are constantly exposed to the sun may be of different quality and have different postharvest characteristics than those on the shady side of the tree or those shaded by leaves. Citrus and mango fruits produced in full sun generally had a thinner skin, a lower average weight, lower juice content, a lower level of acidity but a higher total and soluble solids content (Sites and Reitz 1949, 1950a, 1950b).

Woolf *et al.* (2000) showed that during ripening of avocados at 20 °C, fruit that had been exposed to the sun showed a delay of 2–5 days in their ethylene peak compared with fruits that had been grown in the shade. The side of the fruit that had been exposed to the sun was generally firmer than the non-exposed sides, and the average firmness of exposed fruits was higher than that of shaded fruits. After inoculation with *Colletotrichum gloeosporioides* the appearance of lesions on exposed fruits occurred 2–3 days after shaded fruits. There is also some evidence that citrus fruits grown in the shade may be less susceptible to chilling injury when subsequently kept in cold storage. Specific disorders such as water core in apples and chilling injury in avocado can also be related to fruit exposure to sunlight (Ferguson *et al.* 1999).

Sunsald can occur on fruits that are exposed to the sun; for example, in bananas it can result in damage to the peel that causes discoloration as they ripen (Figure 2). In tomatoes and peppers sunscald is most prevalent on the green fruit, where white or yellow blisters will develop on the sides of the fruit that are exposed to the sun. Continued exposure may result in the damaged areas becoming papery, flattened and greyish with mould growth and eventual rotting. Schrader (2011) described sunburn necrosis on apples where excess solar radiation is converted to heat energy and causes a high fruit surface temperature of about 52 °C resulting in thermal death of cells. He also described a second



Figure 2 Banana sunscald.

type called sunburn browning that is caused by the combination of temperatures of 46–49 °C and high solar radiation. Cell death is not induced, but several pigment changes occur and the apple peel typically turns yellow or brown.

Amarante *et al.* (2002) reported that bagging of pears reduced sunscald. Silimela and Korsten (2000) tested plastic caps with an added inner wool lining to protect mango fruit against sunburn. They found that the capped fruit had significantly less sunburn damage than non-capped fruit. However, Muchui *et al.* (2010a, 2010b) found that in bananas perforated shiny blue bunch covers resulted in a few fingers of top hands of some bunches suffered sunburn. Previously Weerasinghe and Ruwanpathirana (2002) reported that bagging of bananas resulted in sun scorching of the fruits irrespective of the colour of the bunch covers. Pulling leaves over the covered bunches during growth may reduce or prevent sunburn, or inserting a newspaper on the inside of the bunch covers to cover top hands has also been shown to work (Muchui *et al.* 2010a, 2010b). Schrader (2011) reported that a combined sprayable formulation of carnauba wax and organo-clay emulsion was more effective in protecting apples from sunburn browning. Iglesias and Alegre (2006) tested crystal (transparent) and black nets on the protection of apples and found that both nets reduced fruit temperature and the incidence of sunburn improving their skin quality and protecting the fruit from hail damage. They noted some minor effects on fruit quality and their annual cost was €1874 ha⁻¹ for crystal nets and €1612 ha⁻¹ for black nets.

Day length

Day length is related to the number of hours of light in each 24-h cycle, which varies little near the equator but varies between summer and winter in increasing amounts further from equator. Certain crop species and varieties have evolved or been bred for certain day lengths. If this requirement is not met using an unsuitable variety then the crop may still be immature at harvest. An example of this is the onion where cultivars, which have been bred to grow in temperate countries, where the day length is long and progressively getting shorter during the maturation phase, will not mature correctly when grown in the tropics where day length is shorter and less variable during the maturation period. In such cases the onion bulbs had very poor storage characteristics (Thompson 1985). Aborisade and Ayibiowu (2010) studied the effects of day length postharvest on ripened the tomato cultivars Roma and Beske. They were harvested at the mature-green, breaker, turning or pink stages and then stored at 28 °C either in 12 h naturally alternating light and dark or in complete darkness. Ripening progressed in complete darkness more quickly than in 12 h naturally alternating light and dark in breaker fruit. However, the difference was more pronounced in Roma than in Beske. Fruit initially at the turning stage did not show any significant effect of photoperiod in Roma but did by day 6 in Beske. Generally photoperiod had more significant effect at the mature-green and breaker stages than at the turning and pink stages of ripening.

Temperature

The temperature in which a crop is grown can affect its quality and postharvest life. An example of this is pineapple grown in Australia. Where the night-time temperature fell below 21 °C internal browning of the fruit could be detected postharvest (Smith and Glenzie 1987). The recommended storage temperature for Valencia oranges grown in California is 3–9 °C with a storage life of up to 8 weeks. The same cultivar grown in Florida can be successfully stored at 0 °C for up to 12 weeks. Oranges grown in the tropics tend to have a higher sugar and total solids content than those grown in the subtropics. However, tropical grown oranges tend to be less orange in colour and peel less

easily. The latter two factors seem to be related more to the lower diurnal temperature variation that occurs in the tropics rather than the actual temperature difference between the tropics and subtropics.

The apple cultivar Cox's Orange Pippin grown in the United Kingdom can suffer from chilling injury when stored below 3 °C, while those grown in New Zealand can be successfully stored at 0 °C. However, this may be a clonal effect since there are considerable differences in many quality factors, including taste and colour, between clones of Cox's Orange Pippin grown in the United Kingdom and those grown in New Zealand (John Love 1994, personal communication). In Braeburn apples growing conditions were shown to influence scald, browning disorder and internal cavities during storage. So following a cool growing season it was recommended that they should be stored in air at 0 °C to avoid the risks of those disorders, but they may be stored in controlled atmospheres after warm seasons because this retains texture and acidity better (Lau 1998). Ferguson *et al.* (1999) found that in both apples and avocados, exposure of fruits to high temperatures on the tree could influence the response of those fruits to low and high postharvest temperatures. Specific disorders such as water core in apples and chilling injury in avocado can also be related to fruit exposure to high temperatures, disorders such as scald in apples may be related to frequency of low temperature exposure over the season. Oosthuis (1998) found that cool, humid or wet conditions on the date of harvest strongly favour the postharvest development of lenticel damage in mangoes. Conversely, dry, hot conditions discouraged the postharvest development of lenticel damage. Woolf *et al.* (1999) found that Hass avocados exposed to direct sunlight in ambient temperatures of 15–25 °C had a flesh tissue reaching 43 °C. Fruit exposed to the sun had less external damage from hot water treatments of 50 °C for up to 10 min and less external chilling injury when stored at 0.5 °C for up to 28 days. Leakage of electrolytes from skin tissue from fruit exposed to the sun did not increase during storage, while that from shaded fruit increased by about 60%. Also fruit exposed to the sun took longer to ripen than shaded fruit. Mercado-Silva *et al.* (1998) found that guava fruit growth showed a double sigmoid pattern, with spring/summer fruit needing 130 days, while autumn/winter fruit required

190 days to reach the ripe stage. Autumn/winter fruit had higher TSS, TA and ascorbic acid concentrations than spring/summer fruit. The climacteric peaks in respiration rate and ethylene production were reached after 7–8 days in autumn–winter fruit as compared with 4–5 days in spring/summer fruit.

Water relations

High rainfall or heavy irrigation can affect fruit growth which in turn can also increase skin cracking in fruit including cherries, apples and tomatoes. Generally crops that have higher moisture content have poorer storage characteristics. For example hybrid onion cultivars that tend to give high yield of bulbs with low dry matter content but only a short storage life (Thompson *et al.* 1972a, 1972b, Thompson 1985). Srikul and Turner (1995) reported that low irrigation reduced green life of bananas, but if bananas are allowed to mature fully before harvest and harvesting is shortly after rainfall or irrigation the fruit can easily split during handling operations, allowing microbial infection and postharvest rotting (Thompson and Burden 1995). If oranges are too turgid at harvest the oil glands in the skin can be ruptured releasing phenolic compounds and causing oleocellosis (Wardlaw 1937). Some growers harvest crops in late morning or early afternoon. In the case of leaf vegetables such as lettuce they may be too turgid in the early morning and the leaves are soft and more susceptible to bruising (John Love, personal communication). Also too much rain or irrigation can result in the leaves becoming brittle with the same effect. Irrigating crops can have other effects on their postharvest life. In carrots heavy irrigation during the first 90 days after drilling resulted in up to 20% growth splitting, while minimal irrigation for the first 120 days followed by heavy irrigation resulted in virtually split-free carrots with a better skin colour and finish and only a small reduction in yield (McGarry 1993). Shibairo *et al.* (1998) grew carrots with different irrigation levels and found that preharvest water stress lowered membrane integrity of carrot roots, which may enhance moisture loss during storage. The effects of water stress, applied for 45 or 30 days before flowering on Haden mangoes, which were stored at 13 °C for 21 days after harvest, were studied by Vega Pina *et al.* (2000). They found that the 45-day fruits

exhibited a higher incidence and severity of internal darkening, were firmer, contained a higher content of TA and had redder skins than 30-day fruits.

In a study of the storage of onions grown in Tajikistan by Pirov (2001) under various irrigation regimes it was found that if onions are to be used fairly quickly, then maximum yields can be achieved by keeping the soil at 80–90% of field capacity. However, when they were stored for 7 months at 0–1 °C and 75–80% r.h. the best irrigation regime was 70% of field capacity throughout the growing season.

Broccoli, cultivated under low (0.40 MPa) and normal (0.04 MPa, equivalent to field capacity) soil water content, were stored at either 1 °C or room temperature of 23 °C. Low soil water content and storage at 1 °C gave the best preservation of colour, antioxidant activity, l-ascorbic acid and 5-methyl-tetrahydrofolate contents. The phenolic compounds were reduced over time, independent of cultivation and storage conditions (Cogo *et al.* 2012).

Splitting during growth can affect postharvest losses. The incidence of damage in carrots was shown to be affected by the total amount of irrigation and the time when it was applied. Heavy irrigation during the first 90 days after sowing resulted in up to 20% growth splitting, while minimal irrigation for the first 120 days followed by heavy irrigation resulted in virtually no splitting with a better skin colour and finish and only a small reduction in yield (McGarry 1993). Carrots contain an antifreeze protein that improves storage performance. Carrots grown in temperatures of less than 6 °C accumulated higher levels of this protein and subsequently showed less electrolyte leakage from cells, slightly higher dry matter and less fungal infestation than carrots grown in warmer temperatures. However, levels also vary between environments in which the carrots had been grown (Galindo *et al.* 2004, Kidmose *et al.* 2004).

Rachis browning can occur postharvest and Balic *et al.* (2012) studied the effects of various postharvest treatments and found a genetic relationship with this disorder. They suggested a putative cellular regulatory mechanism of water loss and senescence in rachis that most likely involved ethylene and oxidative stress metabolism. They found that cytokinin applied to the fruit 1 day before harvest lowered percentage rachis browning after 90 days at 0 °C plus 2 days at 20 °C compared to those not treated.

Luna *et al.* (2012) studied the effects of five drip irrigation systems (excess 50%, excess 25%, control, deficit 25% and deficit 50%) on the postharvest quality fresh cut iceberg lettuce. They found that visual quality was lower on those from the highest irrigation regime and they had increased off-odours. Also the midrib tissue had a more than 17-fold increase in phenylalanine ammonia lyase activity from the highly irrigated lettuce. They concluded that the quality and shelf life of the fresh cut lettuce were better preserved by reduced irrigation.

Production system

Clearly the system in which a fruit or vegetable is grown including grafting onto rootstocks and pruning can affect its quality and postharvest characteristics. Lower chilling injury occurred in kiwifruit during storage at 0 °C for up to 42 weeks from vines that had been pruned in summer compared to those that had not. There was also less chilling injury in fruit from short shoots compared with those harvested from medium and long shoots. Chilling injury incidence was assessed after 5 days at 20 °C subsequent to storage (Gerasopoulos and Drogoudi 2005). Not much information could be found on the effects of tree age on the postharvest characteristics of fruit, but fruit from young Braeburn apple trees were more susceptible to flesh and core browning than those from older trees (Rabus and Streif 2000). In the tropics flowering time of fruit trees can affect postharvest life of fruits. Mayne *et al.* (1993) have shown that jelly-seed, a physiological disorder of mangoes, was associated with flowering time in Tommy Atkins. They showed that delaying flowering by removing all the inflorescences from the tree greatly reduced jelly-seed in fruit that developed from the subsequent flowering. These fruit were larger than those produced from trees where the inflorescences had not been removed but the number of fruit per tree was reduced.

For various reasons fruit trees are grafted onto rootstocks and the rootstocks can have a profound effect on the performance of the crop, including its postharvest life. Considerable work was done, particularly at Horticultural Research International at East Malling in the United Kingdom and its predecessors, on the use of different rootstocks to control

tree vigour and cropping. Tomala *et al.* (1999) found that the rootstocks had a considerable effect on maturation and storage of Jonagold apples. Fruits from trees on the rootstock B146 had the lowest respiration rates and ethylene production after storage for 2 and 4 months at 0 °C but not after 6 months. Fruits from trees on P60 and 62-396 started their climacteric rise in respiration rate 5–7 days earlier than fruits from PB-4. Fruits were more yellow at harvest from trees on P60, 62-396 and M.26; fruit colour was weak on PB-4 and fruits from these trees coloured most slowly during storage. Rootstocks also affect other fruit crops. In some work in South Africa on avocados (Smith and Köhne 1992) it was shown that the cultivar Fuerte grown on seedling rootstocks showed a large variation in both yield and quality of fruit. There was also some indication that rootstocks, which gave a low yield generally, produced a higher proportion of low quality fruit. Köhne (1992) also showed similar results for the avocado cultivar Hass on different clonal rootstocks (Table 3). Rootstock studies conducted in Australia on Hass avocado by Willingham *et al.* (2001) found that the rootstocks had a significant impact on postharvest anthracnose disease susceptibility. Differences in anthracnose susceptibility were related to significant differences in concentrations of antifungal dienes in leaves, and mineral nutrients in leaves and fruits, of trees grafted to different rootstocks.

Fruits of Ruby Red grapefruit, which had been budded on *Citrus amblycarpa* or rough lemon (*C. jambhiri*) rootstocks, were stored at 4 or 12 °C for 6 weeks by Reynaldo (1999). Losses due to decay and chilling injury were generally lower in fruits from trees budded on rough lemon than on *C. amblycarpa* rootstock and there was an indication that rootstocks affected the metabolic activity of fruits during subsequent storage at 4 °C.

Table 3 Effect of clonal rootstocks on the yield and quality of Hass avocados (source: adapted from Smith and Köhne 1992)

Rootstocks	Yield (kg per tree)	Percentage of fruit internally clean
Thomas	92.7	96
Duke 7	62.1	100
G 755	12.1	100
D 9	7.4	64
Barr Duke	3.1	70

Harvest maturity

As would be expected harvest maturity can have an effect on crop quality. For example Shin *et al.* (2008) found that the overall quality and firmness of Jewel strawberries harvested at the fully red stage declined more rapidly than those harvested at the white tip stage. The initial anthocyanin concentrations of red fruit were about five times greater than that of white tip fruit and declined during the storage. Total flavonoid and phenolic concentrations and total antioxidant activity of fruit harvested at the white tip stage were greater than those harvested at the red ripe stage, and these differences were maintained during storage at 3 or 10 °C for 12 days. Reichel *et al.* (2010) found that for the litchi cultivar Hong Huey the pink to red-shelled harvest maturity stage and for Chacapat the pink-shelled stage provided optimum eating quality and were superior to green-red-shelled breaker stage in long supply chains. Late harvested Braeburn apples were more susceptible to flesh and core browning (Rabus and Streif 2000). Harvey *et al.* (1997) found that *Cucurbita maxima* cultivar Delica harvested at 7 kg force, which occurred between 240 and 300 growing degree days (base temperature 8 °C) from flowering, required a postharvest ripening period to enhance sweetness and texture and to optimize sensory quality that was not necessary for fruits of later harvests. Ahmed *et al.* (2001) found very strong evidence that for Robusta bananas the fruit had much better organoleptic properties the more mature they were when harvested. Medlicott *et al.* (1987a) showed that early maturing mangoes tended to have better quality and postharvest characteristics than those that matured later.

Preharvest infection

Crop hygiene can be important in reducing field infections and infestations that may be carried into storage or the marketing chain. This usually involves removal of rotting material from the field, especially fruit windfalls or tree prunings. It can also involve efficient weed control of species that might be alternative hosts for disease-causing organisms.

Frequently crops are infected with microorganisms or infested with invertebrate pests during production.

They may well be on or in the crop at harvest and taken into storage or through the marketing chain. Almost all postharvest pests originate from field infestations, and if the storage conditions are conducive, they can multiply on or in the crop. Field infestations of yam tubers with parasitic nematode were shown to increase when the tubers were stored in tropical ambient conditions resulting in areas of necrotic tissues. However, when the tubers were stored at 13 °C there was no increase in nematode population in the tubers and no increase in necrosis (Thompson *et al.* 1973). The potato tuber moth (*Phthorimaea operculella*) may infest tubers during growth if they are exposed above the soil. They may also attack tubers postharvest, and it is therefore important to protect the stored tubers to prevent access to them by the moths. Mealy bugs on pineapples occur in the marketing chain from field infestations. Their presence may affect their acceptance on the market or the damage they cause may allow infection by microorganisms that can cause the fruit to rot. *Aspergillus niger* infection in onions occurs during production but will only develop on the bulbs during storage where the conditions are conducive. Infection with bacteria such as *Erwinia carotovora* can occur in the field on vegetables and cause postharvest soft rots especially where they have been damaged (Thompson *et al.* 1972a, 1972b).

Youssef *et al.* (2012a) sprayed aqueous salt solutions at 2%, w/v, 20 hl ha⁻¹ to citrus trees. After harvest fruit were stored at 4 ± 1 °C and 95–98% r.h., followed by 7 days of shelf life at 20 ± 2 °C. They reported that the preharvest application of sodium carbonate, potassium carbonate and sodium silicate completely inhibited the incidence of decay as compared to the water control. When the salts were applied after harvest, the activity was in general less pronounced with sodium carbonate and potassium carbonate being the most effective. In Yemen the control of anthracnose on papaya was achieved by preharvest sprays with Metiram 80% wettable powder at 200 g 100 L⁻¹ of water or Propineb 70% at 200 g 100 L⁻¹ of water or copper oxychloride 50% wettable powder at 400 g 100 L⁻¹ water applied at 7–10 days intervals (Kamal and Agbari 1985). Kobiler *et al.* (2011) reported that in Israel, black spot caused by *Alternaria alternata* was the main postharvest factor that impaired the quality and reduced the storability of the persimmon

cultivar Triumph. The fungus infects the fruit in the orchard and remains quiescent until harvest. After harvest, the pathogen slowly colonizes the fruit during storage at 0 °C, which elicits black spot symptom development after 2–3 months of storage. A commercial postharvest dip in at 500 mg L⁻¹ chlorine released from sodium troclosene tablets effectively controlled black spot in fruit stored for up to 2 months, but decay incidence increased after 2½ months of storage. Preharvest treatment with a single spray with the curative fungicide polyoxin B 14 days before harvest in combination with the postharvest chlorine dip treatment reduced the black spot infected area by 60%, compared with the chlorine dip alone. Post-storage on-line spraying with sodium troclosene, applied in combination with the postharvest chlorine dip, improved the percentage of marketable fruit by 10%, compared with the postharvest chlorine dip alone, but treatment just prior to marketing may not be permitted in many countries.

The control of pests and diseases is commonly achieved by spraying chemicals directly onto the crop, although this is becoming less with increasing use of techniques such as integrated pest management and integrated crop management. The control of field infection can have considerable effect on the postharvest life of the crop. An example of this is anthracnose disease that is caused by field infection by the fungus *Colletotrichum gloeosporioides* [*Glomerella cingulata*], which if not controlled it can cause rapid postharvest losses (Thompson 1987). The fruits look perfectly healthy at harvest and the disease symptoms develop postharvest. The time between infection and the symptoms of the disease developing may be lengthy for example anthracnose (*C. musae*) in bananas can take over 5 months (Simmonds 1941). Generally if a crop has suffered an infection during development its storage or marketable life may be adversely affected. Bananas may ripen prematurely or abnormally after harvest because of leaf infections by fungi during growth, which caused stress and therefore shortened their storage life. This can be manifested on the crop before harvesting or it may only be observed as a physiological disorder postharvest. Fungicide applications in the field to control Sigatoka leaf spot (*Mycosphaerella musicola*) were shown to reduce premature ripening (Thompson and Burden 1995).

Growth regulation

Daminozole

Growth regulators have been applied to trees to increase fruit quality and yield. One such chemical, which has been the subject of considerable debate in the news media, is Daminozide (*N*-dimethylamino succinamic acid), also called Alar, B9 or B995. When applied to Cox's Orange Pippin apples at 2500 $\mu\text{L L}^{-1}$ in late June and mid-August, they developed redder colour in the skin and were firmer than unsprayed fruits (Sharpley 1967). Sprayed fruit were less susceptible to *Gloeosporium* rots but had more core flush during storage. There was some indication that sprayed fruits were slower to mature since Daminozide tended to retard the climacteric rise in respiration. In a comparison between preharvest and postharvest applications of daminozide to Cox's Orange Pippin apples, immersion of fruits in a solution containing 4.25 g L^{-1} for 5 min delayed the rise in ethylene production at 15 °C by about 2 days, whereas orchard application of 0.85 g L^{-1} caused delays of about 3 days (Knee and Looney 1990). Both modes of applications depressed the maximal rate of ethylene production attained by ripe apples by about 30%. Daminozide-treated fruit were also shown to be less sensitive to ethylene in the storage atmosphere than untreated fruit, but this response varied between cultivars (Knee and Looney 1990). Daminozole has been withdrawn from the market in several countries.

Gibberellic acid

When the fungus *Gibberella fujikuroi* infects rice plants it was observed to cause long spindly growth that was called bakanae in Japan. Yabuta and Sumiki (1938) isolated the metabolic products of the fungus and described the plant growth regulator that caused the effect and called it gibberellin. Subsequent work showed that it was not a single substance, and several gibberellins have been described including gibberellic acid called GA_3 . Preharvest sprays of GA_3 have been shown to have effects on the postharvest of fruit and vegetables. These include reduced yellowing and extended storage life of parsley (Lers *et al.* 1998), reduced chilling injury in persimmon (Besada *et al.* 2008), decreased fruit cracking in cherry (Yildirim and Koyuncu 2010) and delayed fruit ripening and

reduced decay in cactus pear (Schirra *et al.* 1999a). Postharvest treatment with has been shown to reduce degreening in lemons (Mizobutsi *et al.* 2000) and limes (Sposito *et al.* 2000) and has been shown to improved retention of vitamin C also in limes (Keleg *et al.* 2003). A negative effect of GA_3 was reported by Zoffoli *et al.* (2009) who found that it could induce shatter and predisposed grapes to grey mould caused by *Botrytis cinerea*.

AVG

AVG, also called aminoethoxyvinylglycine ([S]-trans-2-amino-4-(2-aminoethoxy)-3-butenic acid hydrochloride), is an ethylene biosynthesis inhibitor. Effects of both 100 and 200 mg L^{-1} AVG applied 2 weeks before harvesting plums decreased their firmness during subsequent storage compared to those not treated. Also with the 100 mg L^{-1} AVG treatment there was a decrease in their total phenolics and total antioxidant activity. They concluded that AVG treatments generally had negative impacts on individual phenolic compounds (Ozturk *et al.* 2012). Mission muskmelon harvested from plots sprayed with AVG had lower rates of ethylene production at harvest and after cold storage than melons harvested from control plots. Melon ethylene production after storage was consistently lower when AVG was applied 7 days after full net formation, especially at the highest rate of 260 mg L^{-1} . AVG delayed initial development of an abscission zone but increased leaf chlorosis, and had no effects on flesh firmness, soluble solids, fresh mass or incidence of decay at harvest or after storage (Shellie 1999). AVG at 1 g L^{-1} reduced ethylene production, respiration rate and softening of apricots (Muñoz-Robredo *et al.* 2012). Lulai and Suttle (2004) found that treatment of potato tubers with AVG-inhibited wound-induced ethylene production by about 90%, but did not affect wound-induced suberization.

Ethylene

Ethrel, also called Ethephon, has been used as a source of ethylene for decades and it is used to initiate flowering in pineapples. It has also been applied just before harvesting to accelerate degreening and therefore the development of the orange colour in the skin. In Queensland Smooth Cayenne pineapples

treated prior to harvest with Ethrel at a concentration of $2\frac{1}{2}$ L in 1000 L of water had superior eating quality, degreened more evenly, but had a shorter shelf life owing to accelerated skin senescence than untreated fruit 10 days after harvest. Treated fruit left on the plant for 23 days had inferior eating quality than the untreated fruit (Smith 1991). These effects are probably due to the effect of the ethylene speeding up the maturation of the fruit.

Maleic hydrazide

Chemicals may also be applied to certain crops in the field to prevent them sprouting during storage and thus to extend their storage period. An example of this is the application of maleic hydrazide to onions. Because it is necessary for the chemical to be translocated to the apex of the growing point towards the centre of the bulb, it has to be applied to the leaves of the growing crop some 2 weeks before harvesting so that the chemical has time to be translocated into the middle of the bulb into the meristematic

tissue (Thompson 1986). Maleic hydrazide should be applied according to the manufacturer's instructions but $2500\text{ }\mu\text{L L}^{-1}$ sprayed on the crop shortly before the leaves die down was recommended by Tindall (1983).

Other chemicals

In Trinidad preharvest spraying of sweet potatoes with maleic hydrazide or treating the tubers postharvest with MENA (methyl ester of naphthalene acetic acid) has been reported to inhibit sprouting. MENA was applied by interleaving it with layers of paper soaked in MENA in acetone at a ratio of 40 ml 100 kg^{-1} tubers (Kay 1987). Paton and Scriven (1989) applied NAA (naphthaleneacetic acid) either under reduced pressure as a 1 g L^{-1} solution containing a wetting agent or as a dust of 1, 10 or 100 mg g^{-1} of talc. During storage of at least 40 days NAA applied as a solution reduced sprouting by more than 50% and when it was applied in talc the reduction in sprouting was 29%. However, in both cases there was an increase in water loss.

2

Assessment of crop maturity

The principles that underlie at which stage of maturity a fruit or vegetable should be harvested are crucial to its quality as well as its subsequent storage and marketable life. Maturity may be defined in terms of either their physiological maturity or their horticultural maturity and are based on the measurement of various qualitative and quantitative factors. There are certain guiding principles to be followed when selecting fruit or vegetables to be harvested. Harvest maturity should be at maturity that:

- allows them to be at its peak condition when they reach the consumer
- allows them to develop an acceptable flavour or appearance
- allows them to have an adequate shelf-life
- gives a size acceptable to the market
- is not toxic.

The methods used to assess the maturity of produce may be based on the subjective estimate of people carrying out the operation. To achieve this, sight, touch, smell, morphological changes and resonance may be used. These methods may be made more objective and perhaps more consistent by the use of aids such as colour charts (Figure 3). Chemical and physical analyses are also used. These depend on sampling procedures and can therefore be used only on crops where a small representative sample can be taken. Computation is also used by calculating such factors as time after flowering as a guide to

when to harvest fruit. Many of the methods, which use a qualitative attribute of the crop, may also be used to determine its postharvest quality. Almost all the measurements described here can also have that function.

Field methods

Skin colour

Skin colour is used for fruit where changes occur as the fruit ripens or matures, but in some fruits there are no perceptible colour changes during maturation. Colour changes may occur on particular cultivars but not on others. Also with some tree fruit colour of skin may be partly dependent on the position of fruit on the tree or the weather conditions during production, which may confound its use as a maturity measurement. There are many examples of the commercial use of skin colour as the determinate of harvest maturity. For apricots Fan *et al.* (2000) defined maturity stage 1 as light green, partially turning to a straw colour and maturity stage 2 as straw colour on most of the fruit surface. In South Africa the Deciduous Fruit Board produced a colour chart for apricots. For loquat Hamazu *et al.* (1997) described eight stages of harvest maturity from stage 1 (green, small) through to stage 7 (yellowish orange) and stage 8 (slightly over ripe) and indicated that stage 7 is the optimum harvest maturity. In mangosteen harvest maturity is



Figure 3 Colour chart to facilitate colour grading of tomatoes. (Source: OECD 2003. Reproduced with permission.) See colour plate section.

normally judged on the skin colour, which changes from green as it matures. The Malaysian Agricultural Research and Development Institute published a colour chart of changes in skin colour of mangosteens. In Indonesia Daryono and Sosrodiharjo (1986) found that the best time for harvesting was when 25% of the fruit skin had developed a purple colour. Sugar content, acidity, sugar:acid ratio and ascorbic acid content were 14.3%, 0.46%, 31.3 and 42.3 mg 100 g⁻¹, respectively, at harvest. Impact injury during harvesting and handling can damage the fruit (Tongdee and Suwanagul 1989). Mercado-Silva *et al.* (1998) found that the best maturity index for the guava cultivar Media China was colour with fruit with a yellowish green external colour was optimum. Instrumental methods of measuring the colour of fruit have been used for many years and commercial colour sorters have been used on packing lines for many crops (Figure 4).

Shape

The shape of fruit can change during maturation and this can be used as a characteristic to determine harvest maturity. In bananas the individual fruit become more rounded in cross section and less angular as they develop on the plant. In Kenya Muchui *et al.* (2010a, 2010b) found a good correlation for Grande Naine and Williams bananas between bunch age, finger diameter, pulp to peel ratio and TSS. On that basis they recommended that the best maturity indices for determining the harvest time might be a combination



Figure 4 An on-line colour sorting machine being used on potatoes.

of bunch age and finger diameter. Mangoes also change shape during maturation on the tree. On very immature fruits the shoulders slope away from the fruit stalk; on more mature fruit the shoulders become level with the point on attachment and on even more mature fruit the shoulders may be raised above the point of attachment. Using this method of determining mango fruit maturity Thompson (1971a, 1971b, 1971c) showed that the percentage of fruit still unripe after storage at 7 °C for 28 days was 68% for fruit with sloping shoulders, 57% for fruit with level shoulders and 41% for fruit with raised shoulders. In peaches and nectarines fruit shape is used when their shoulders and the suture are well developed and filled out they are considered sufficiently mature for harvesting (Lill *et al.* 1989).

Size

The changes in size of a crop as it is growing are frequently used to determine when it should be harvested. In fruits this may simply be related to the market requirement and the fruit may not be physiologically mature for example in capsicums and aubergine. Partially mature cobs of *Zea mays* var. *saccharata* are marketed as sweetcorn while even more immature, and thus smaller, cobs are marketed as baby corn. In some crops fibres develop as they mature and it is important that they are harvested before this occurs. In crops such as green beans, okra and asparagus this relationship may be related to its size. In bananas the width of individual fingers can be used for determining their harvest maturity. Usually

Table 4 Effects of harvest maturity of litchi, as measured by fruit diameter, on weight, price and income from the fruit where 100 is a comparative base (source: adapted from Blumenfeld 1993a,b)

	Fruit diameter (mm)		
	60	65	70
Weight	100	120	140
Price	100	115	130
Income	100	138	182

a predetermined finger from the bunch is used and its maximum width is measured with callipers, hence it is referred to as the *calliper grade*. The length of the same finger may also be measured for the same purpose. Both these measurements are often used as quality criteria during marketing of fruit. Fruit size can also be used for determining the harvest maturity of litchi. In South Africa it was shown that the size of the fruit at harvest could have a very big effect on its profitability during marketing (Table 4). However, the longer the fruits were left to mature on the tree, the higher the postharvest losses, but even if 70 mm diameter fruit were harvested and had postharvest losses, it may still be economic to harvest at this stage (Blumenfeld 1993a). In longan fruit size and weight were consistently shown to have a high correlation with eating quality. In Thailand Reichel *et al.* (2010) found that fruit size of litchi and also titratable acids contributed most to the specification of harvest maturity among the seven attributes they evaluated with the cultivars Hong Huey and Chacapat.

Aroma

Most fruits synthesize volatile chemicals as they ripen. These may give the fruit its characteristic odour and can be used to determine whether a fruit is ripe or not. These odours may only be detectable to human senses when a fruit is completely ripe and therefore have limited use in commercial situations. This applies to several types of fruit, but in practice they are used in association with other changes. Equipment fitted with aroma sensors has been developed for postharvest measurement of fruit ripeness.

Computation

The time between flowering and fruit being ready for harvesting may be quite constant. For many fruit

crops grown in temperate climates, such as apples the annual optimum harvest date may vary little from year to year, even though the weather conditions may be quite different. In apples the time of petal fall may be recorded, which gives an approximate guide to when fruit should be harvested. In tropical fruit, flowering may occur at various times of the year, but the time between flowering and maturity may vary very little. With most fruit it is difficult to utilize this consistency in practice. In mangoes, for example, if flowers or young fruit are marked or tagged so as to identify their flowering or fruit-set time, they almost invariably shed that fruit before it is fully developed. In bananas it is different. At anthesis a plastic cover is placed over the bunch to protect the fruit as it is developing. In order to identify exactly when anthesis occurred, a coloured plastic ribbon is attached to the bunch. The same colour is used for 1 week and changed to another colour the following week and so on. This means that at the harvest time the age of the bunch is precisely known. Wilson Wijeratnum *et al.* (1993) showed that the Ambul variety of banana grown in Sri Lanka reached physiological maturity in 8–9 weeks after the flowers had opened. Fruit growth and development continued until the 13th week but changes in other physical and chemical parameters were minimal after 11 weeks. In Ecuador the maximum time from anthesis to harvest is usually 12 weeks, in the Windward Islands it is 13 weeks. Harvest maturity for rambutans may be judged on the time after full flowering. In Thailand this is 90–120 days, in Indonesia 90–100 days and in Malaysia 100–130 days (Kosiyachinda 1968). In New Zealand optimum harvest maturity of kiwifruit was some 23 weeks after flowering (Pratt and Reid 1974). Kienzle *et al.* (2012) evaluated harvesting at 83–107 days after full bloom for the mango cultivar Chok Anan and found that harvesting 89 days was the optimum maturity in terms of maximizing postharvest life while developing good quality eating ripeness at 14 °C.

In New Zealand optimum harvest maturity of kiwifruit is some 23 weeks after flowering (Pratt and Reid 1974). For carambola fruits harvested 10 or 11 weeks after fruit set could be stored for about 2 weeks at 5 or 10 °C before disease began to develop, but conversely fruits harvested 12 or 13 weeks after fruit set could be successfully stored for 4 weeks at 5 or 10 °C (Osman and Mustaffa 1996). Fruit development

in Florida takes 60–70 days to reach harvest maturity. Fruits harvested too early tend to brown severely during storage (Campbell 1989). The time after flowering can also be used to determine harvest maturity in mango. In India Alphonso exhibited a sigmoid pattern of growth and took 16 weeks from fruit set to attain harvest maturity (Rao *et al.* 1995). Rajput *et al.* (1999) showed that the fruit growth of the cultivars Langra, Sunderja, Mallika and Amrapali also followed a sigmoid pattern, and in general it was rapid between 30 and 90 days after fruit set. Kienzle *et al.* (2012) evaluated harvesting mangoes 83–107 days after full bloom for the cultivar Chok Anan. They found that fruit that were harvested 89 days after full bloom and stored at 14 °C and 50–60% r.h. with ethylene absorption took 18 ± 1 days to reach eating ripeness.

Mangoes of the cultivars Karuthacolomban, Velleicolomban and Willard, grown in Sri Lanka, were harvested at 10, 11, 12 and 13 weeks after flowering. Peel colour development could be used to determine harvest maturity in Willard. Changes of dark green to light green with maturity could not be considered a reliable index for the other two cultivars. Rising of shoulders with maturity was a better indicator of maturity than peel colour development, and it could be used as a reliable index to harvest all three cultivars. Though mature fruits of Willard and Velleicolomban passed the float test, Karuthacolomban did not respond consistently. The mean value of total soluble solids recorded from Karuthacolomban and Velleicolomban harvested 13 weeks after flowering was 18 °Brix, while titratable acidity was 0.3%. Total soluble solids and titratable acidity of Willard were similar to these values in the 12th week after flowering. The fruits harvested before the optimum stage of maturity contained significantly lower total soluble solids, higher titratable acidity and poorer sensory properties than mature fruits (Amarakoon *et al.* 1999).

Leaf changes

This is a characteristic that is used in both fruit and vegetables to determine when they should be harvested. In many root crops the condition of the leaves can indicate the condition of the crop below ground. If potatoes are to be stored then the optimum harvest time is after the leaves and stems have died

down. If they are harvested earlier the skins are less resistant to harvesting and handling damage and are more prone to storage diseases. Bulb onions that are to be stored should be allowed to mature fully before harvest, which is judged to when the leaves bend just above the top of the bulb and fall over. When the leaf dies in whose axis a fruit is borne in melons then that fruit is judged to be ready for harvesting. In some cucurbits when the leaf, in whose axis the fruit has been produced, dies this may be an indication that the fruit is sufficiently mature for harvesting.

Abscission

As part of the natural development of fruit an abscission layer is formed in the pedicel. This can be judged by gently pulling the fruit. However, fruit harvested at this maturity will be well advanced and have only a short marketable life.

Firmness

Fruit may change in texture during maturation and especially during ripening where they may rapidly become softer. Excessive loss of moisture may also affect the texture of crops. These textural changes may be detected by touch, and the harvester may simply be able to gently squeeze the fruit and judge whether to harvest it. A non-destructive firmness test was investigated at Cranfield University, which simulated the practice of customers who may test a fruit's ripeness by feeling it. A narrow metal cylindrical probe was pressed onto the skin of the fruit (approximately 1 N was sufficient), and the amount of the depression of the skin was very accurately measured on an Instron Universal Tester (Curd 1988, Allsop 1991). This was found to correlate well with maturation and ripening of the fruit and also caused no detectable damage. Similar studies had previously been carried out by Mehlschau *et al.* (1981) who used steel balls, one each on opposite sides of the fruit, to apply a fixed force. They then measured the deformation that was caused to the surface of the fruit. Perry (1977) described a device, which applied low pressure air to opposite sides of fruit and then measured the surface deformation. Corrêa *et al.* (2004) reported a modified version of a pressure tester with a double plate that allowed flesh firmness to be measured in Hass avocados and cherimoya. They also reported that a puncture test, used to measure skin resistance, can also be

considered an indicator of maturity degree in Hass avocados.

Firmness, or what is usually called solidity, can be used for assessing harvest maturity in many leafy vegetables. The harvester who slightly presses vegetables such as cabbages and hearting lettuce with his or her thumb and fingers can do this by hand. Harvest maturity is assessed on the basis of how much the vegetable yields to this pressure. Normally the back of the hand is used for testing the firmness of lettuce in order to avoid damage (John Love, personal communication).

Postharvest methods

Sugars

In climacteric fruit carbohydrates are accumulated during maturation in the form of starch. As the fruit ripens starch is broken down into sugars. In non-climacteric fruits it is sugars not starch that are accumulated during maturation. In both cases it follows that measurement of sugars in the fruit can provide an indication of the stage of ripeness or maturity of that fruit. In practice the soluble solids

(TSS), also called °Brix, is measured in the juice of samples of fruit because it is much easier to measure. Usually sugars are the soluble solids that are in the largest quantity in fruit. So measuring the TSS in samples of the juice can give a reliable measure of its sugar content. This is done either with a suitable Brix hydrometer or in a refractometer (Figure 5). This factor is used in certain parts of the world to specify maturity of, for example, kiwifruit, honeydew melons, peaches and longan. In kiwifruit OECD (1992) stipulated that the minimum TSS content should be 6.2% based on the average of 10 sample fruit. Crisosto *et al.* (2012) reported that the minimum harvest maturity standards for the cultivar Hayward were 5.5 to 6.5% TSS, which assures adequate storage potential to avoid flesh breakdown and that they would ripen to a good flavour. Tongdee (1997) indicated that soluble solids could be used to determine harvest maturity of litchi using 15.5–16 °Brix. For grapes the optimum TSS at harvest varies between cultivars for example Pantastico (1975) reported that it should be 18–20% for Thompson Seedless and 12–14% for Bangalore Blue. In Lithuania Kviklienė *et al.* (2011) calculated harvest maturity as: firmness divided by TSS and for the cultivar Lodel the optimum was 0.20–0.13.

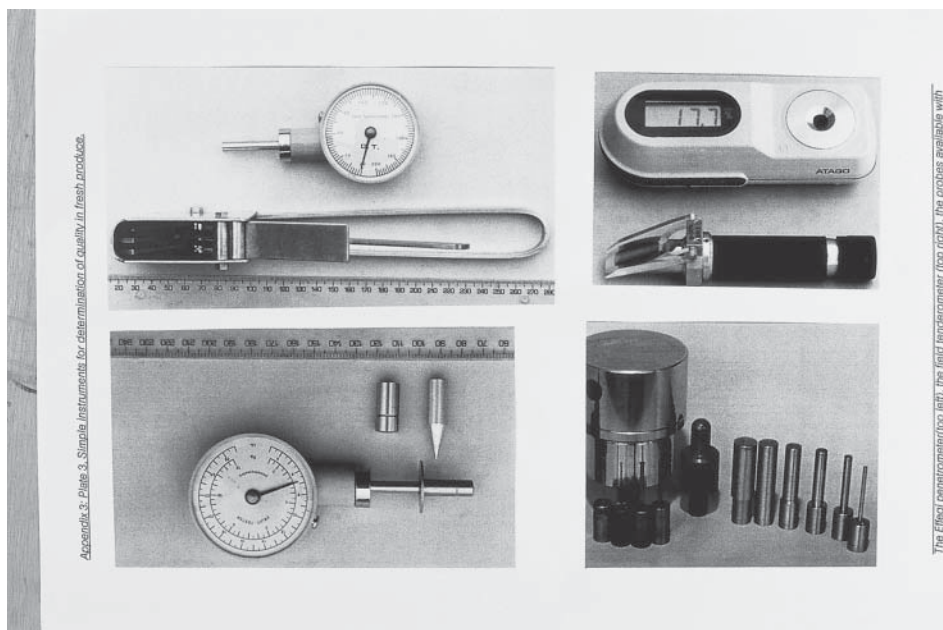


Figure 5 Texture measuring equipment, also with refractometers at the top right. (Source: Ssemwanga 1990. Reproduced with permission of Cranfield University.)

Starch

In apple and pears carbohydrates are accumulated during maturation in the form of starch. Starch is converted into sugar as harvest time is approached. The measurement of starch content in the developing fruit can provide a reliable method for assessing its harvest maturity, but it does not work for all cultivars. In Poland it was described for pears, but there was considerable variation between cultivars and it also varied over the two seasons when it was evaluated (Table 5). Measurement of starch involves taking a representative sample of fruit from the orchard as the harvest time approaches. These fruit are cut into two and the cut surface dipped in a solution containing 4% potassium iodide and 1% iodine. The cut surface will be stained a blue-black colour in the places where starch is present. It is possible, often with the use of Perspex templates marked with concentric rings, to determine the percentage starch (Figure 6). In Turkey prepared charts have been developed for several popular cultivars (Figure 7). In practice, in England, samples would be taken from pears from mid-August, when the whole fruit surface should contain starch and harvesting should be carried out when samples show about 65 to 70% of the cut surface which has turned blue-black (Cockburn and Sharples 1979). Studies using this technique on apples gave inconsistent results in England, but it was very effective on several cultivars in Turkey. Wawrzyńczyk *et al.* (2006) reported that there was a slight statistically non-significant increase in TSS of pears during CA storage in both 2003/2004 and 2004/2005. This increase may have been due to starch degradation, especially in Delbuena, which had a starch index of 1 at harvest time. The only cultivar to show a slight, but statistically non-significant decrease in TSS content



Figure 6 The starch iodine test used to determine the harvest maturity of pears and apples. (Source: Dr R.O. Sharples.)

was Nojabrska, which had a starch index of 10 at harvest time.

Dry matter

Dry matter has been used to relate harvest maturity with quality. Saranwong *et al.* (n.d.) reported that dry matter and starch could be used as harvesting indices for hard green mangoes as they had a strong relationship with the level of TSS of ripe eating quality, while individual sugars and fruit density did not. Crisosto *et al.* (2012) reported that researchers from various countries have proposed using dry matter at harvest as a worldwide quality index for Hayward kiwifruit, because it includes sugars, acids, structural carbohydrates and starch and did not change postharvest. They carried out consumer tests over several years which indicated that dry matter and acidity of ripe fruit were related to consumer acceptance of kiwifruit. In most California seasons, when ripe TA was less than 1.2%, only a dry matter greater

Table 5 Starch index for six Polish pear cultivars at harvest during two seasons, where 1 = black (maximum starch) and 10 = white (no starch) (source: adapted from Wawrzyńczyk *et al.* 2006)

Cultivar	Season 2003/2004		Season 2004/2005	
	Harvest date	Starch index	Harvest date	Starch index
Alexander Lukas	September 17	5.9	September 20	7.5
Amfora	September 17	5.2	October 6	9.4
Delbuena	September 10	1.0	September 20	1.0
Delmoip	September 10	6.4	September 27	6.7
Erica	September 17	6.7	October 6	10.0
Nojabrska	September 22	9.8	October 4	10.0

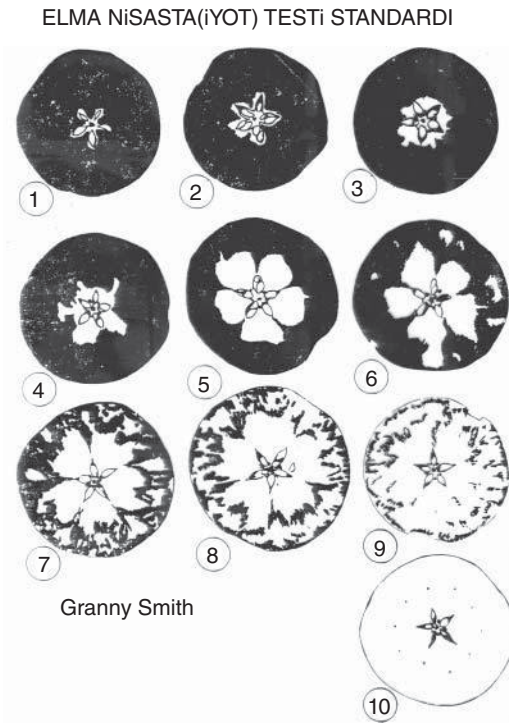


Figure 7 Starch iodine test template used for apples in Turkey where 1 is cut surface completely turned blue/black and 10 with none of the cut surface turned blue/black.

than or equal to 15.1% was required for consumer acceptability. They found that their results provided strong evidence that dry matter would be a reliable quality index candidate for California kiwifruit, especially if TA of ripe fruit was factored in.

Firmness

In some cases a representative sample of fruit may be taken from the orchard and tested in a device which will give a numerical value of texture; when that value reaches a predetermined critical level then the fruit in that orchard are all harvested. These pressure testers were first developed for apples (Magness and Taylor 1925) and are currently available in various forms (Figure 5). Firmness is commonly expressed as kgf (kilograms force). Hand-held pressure testers could give variable results because the basis on which they are used to measure the firmness of the crop is affected by the angle at which the force is applied. An experienced operator may be able to

achieve consistent and reliable results, but greater reproducibility can be achieved if the gauge for measuring firmness is held in a stand so that the angle of force applied to the crop is always constant. The speed with which the probe presses against the fruit can also affect the measurement of firmness, so instruments have been developed which can control it. The performance of a firmness penetrometer developed by DeLong *et al.* (2000) was evaluated over two growing seasons with post-storage apples against the Effegi, Magness–Taylor and electronic pressure tester. Highly significant instrument by operator interactions indicated that the influence of operators on instrument performance was not consistent but overall the newly developed penetrometer performed as well or better than the other instruments tested. In a comparison between a penetrometer (puncture) test and a flat plate compression test Sirisomboon *et al.* (2000) found that the penetrometer was superior for analysing the texture of Japanese pears. A computer-assisted impact-testing device with a 49.29 g stem and a 0.04 m height was used to test the firmness of Hass avocados. Impacts proved to be non-destructive under these conditions and therefore they could be used to determine their ripening stage (Corrêa *et al.* 2004). Pressure tests can be used for plums but Hulme (1971) commented that it is usually easier to test texture by feel. Perry (1977) described a device that applied low-pressure air to opposite sides of plums to measure the surface deformation for assessing fruit firmness. Another non-destructive technique for assessing the harvest maturity uses a ballistic collision technique (Harvey *et al.* 1995). In crops such as peas a shear cell is used to measure texture and is called a tenderometer (Knight 1991). Pressure testers used for fruits and tenderometers are destructive tests which assume that the sample taken is representative of the crop. Shmulevich *et al.* (2003) described a low-mass impact firmness tester produced by the USA Sinclair International Company for measuring firmness of avocados. Valero *et al.* (2007) also used the Sinclair iQTM firmness tester for a non-destructive test and a modification of the Magness and Taylor type penetrometer for their destructive measurements. They tested the relationship between these two methods and characterized them in terms of segregating peaches, nectarines and plums according to their stages of

ripening by discriminant analysis. Discriminant analysis consistently segregated non-destructive firmness measured fruit into different classes. They concluded that both destructive and non-destructive firmness measurements can be directly used to identify the stage of ripeness and potential susceptibility to bruising during postharvest changes.

Juice

The juice content of many fruits increases as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit it is possible to specify its maturity. In some countries legislation exists which specifies the minimum juice content before fruit can be harvested (Table 6).

Oil

This is probably only applicable to avocados where the oil level increases as the fruit matures on the tree. Also it is only applicable to those grown in the subtropics. This is because it is based on a sampling technique where it is assumed that the sample of fruit on which the oil analysis has been taken is representative of the whole field. In the subtropics there are distinct seasons, and flowering of avocados occurs after a cold season and the trees tend to flower and thus set fruit over a short period of time. Trees of the same variety in one orchard will have fruit that therefore mature at about the same time and so a representative sample can be taken. In the tropics the flowering period, even on the same tree, is over a much more protracted period and so there is a wide range of fruit maturities. It is rarely

possible, therefore, to obtain a representative sample. In California Kader and Arpaia (2006) reported that the correlation between dry weight ratio and oil content was used as a maturity index, and minimum dry weight ratio should range between 19 and 25%. They also reported that at harvest the minimum of 8% oil content was specified as standard, and there was a correlation between dry weight and oil content.

Acidity

The acidity of many types of fruit changes during maturation and ripening. In many fruit acidity progressively reduces as the fruit matures on the tree. Taking samples of these fruit, extracting the juice and titrating it against a standard alkaline solution give a measure that can be related to optimum time of harvest. It is important to measure acidity by titration and not by measuring the pH of the fruit because of the considerable buffering capacity in fruit juices. Normally acidity is not taken as a measurement of fruit maturity by itself. It is usually related to soluble solids giving, what is termed, the °Brix : acid ratio. For example Lill *et al.* (1989) showed that TA in peaches and nectarines varied with cultivar and season, and the ratio of TSS : TA was found to be more closely related to quality than TA or TSS alone but it still varied between years.

Specific gravity

Specific gravity of solids or liquids is the relative gravity or weight compared to pure distilled water at 16.7 °C, which is reckoned to be unity. By comparing the weights of equal bulks of other bodies with the weight of water their specific gravity is obtained. In practice the fruit or vegetable is weighed in air and then in pure water, and its weight in air is divided by the loss in weight in water thus giving its specific gravity. As fruit mature their specific gravity increases. This parameter is rarely used in practice to determine when to harvest a crop but it could be where it is possible to develop a suitable sampling technique. It is used, however, to grade crops into different maturities postharvest. To do this the fruit or vegetable is placed in a tank of water and if they float they will be less mature than those

Table 6 The minimum juice content levels for citrus fruits harvested in the United States

Type of citrus fruit	Minimum juice content (%)
Navel oranges	30
Other oranges	35
Grapefruit	35
Lemons	25
Mandarins	33
Clementines	40

which sink. To give greater flexibility to the test and make it more precise, a salt or sugar solution can be used in place of water in the tank. This changes the density of the liquid resulting in fruits or vegetables that would have sunk in water, floating in the salt or sugar solution. Lizada (1993) showed that a 1% sodium chloride solution was suitable for grading Carabao mangoes in the Philippines. Also in Thailand it was found that an increase in fruit density or specific gravity was well correlated with eating quality in mangoes (Kudachikar *et al.* 2001).

Diffuse light transmission

A strong light can be shone on a fruit, some of which may actually diffuse through it and can be collected and measured on the other side of the fruit. These light transmission properties of fruit can be used to measure their ripeness. The wavelength of peak transmittance of light through fruits was shown to have good correlation with their maturity (Birth and Norris 1958). This was tested on tomatoes, and a portable easy-to-use instrument was developed which was non-destructive and could be used on several types of fruit that reduces during maturation. In apricots the correlation coefficients were in the range of 0.84–0.93. The transmission of near-infrared light has been used as a non-destructive method for measuring the soluble solids content of cantaloupe melons (Dull *et al.* 1989). Czabaffy (1984, 1985) measured diffuse light transmission in the range of 380–730 nm through cherries and found that it was shown to be affected by the level of chlorophyll in the fruit. Chlorophyll decreases during maturation so this could be used as a maturity measurement.

Delayed light emission

Colour sorting equipment is commercially available for use in packhouses. Delayed light emission (DLE) is detectable for times ranging from milliseconds to many minutes and is induced by back reactions of the photosynthetic pathway and therefore requires functional chloroplasts. It is detectable only in the dark following light excitation. It yields very low energy and decays very rapidly (Abbott *et al.* 1994). Essentially DLE is used to measure chlorophyll content

of fruit, which not only varies with maturity of the fruit but can also vary with cultivar. DLE measurements require selection of duration and intensity of illumination, dark period and temperature for each cultivar tested. DLE has been used on fruits such as Satsuma oranges (Chuma *et al.* 1977), bananas (Chuma *et al.* 1980a, 1980b), tomatoes (Forbus *et al.* 1985) and papaya (Forbus *et al.* 1987) to grade fruit objectively into different maturity groups postharvest. The fruit is exposed a bright light inside a dark enclosed compartment and then the light is switched off so the fruit is in the dark. A sensor measures the amount of light emitted from the fruit, which is proportional to its chlorophyll content and thus to its maturity.

Twist tester

Studman and Yuwana (1992) described a twist tester developed at Massey University in New Zealand. It consisted of a blade fixed at 90° to a horizontal spindle. The fruit was pushed onto the spindle and rotated around the spindle until the blade crushes the flesh and the fruit turns freely. The angle that the fruit rotated before tissue failure was measured using a potentiometer and this angle then was converted into a crushing strength using formulas. Essentially the twist tester measures firmness as crush strength by radial movement of a small calibrated blade at any point. In non-peeled nectarine fruit Griessel (1995) showed the differences in rate of softening between the inner and outer mesocarps and was used in the determination and prediction of harvest maturity for the cultivar May Glo. It has also been successfully used on kiwifruit.

Body transmittance spectroscopy

Body transmittance spectroscopy was used for optical grading of papaya fruits into ripe and not ripe groups (Birth *et al.* 1984). With this method it was possible to grade fruits that were indistinguishable by visual examination.

Photoelectric

A photoelectric machine was used for colour sorting citrus fruit (Jahn and Gaffney 1972). They used ESM

model G and were able to separate oranges and limes into different classes on the basis of their chlorophyll levels. Watada (1989) has expressed transmittance data on scattering samples:

$$\text{optical density} + \log_{10}(E_o/E)$$

where

E_o = the incident energy

E = the transmission energy.

Diffuse reflectance

Diffuse reflectance measures the reflected light just below the surface of the crop. It was shown to be effective with persimmon with a diffuse reflectance of 680 nm suitable for automatic grading lines (Chuma *et al.* 1980a). In lettuce there was a shift in diffuse reflectance from 640–660 to 700–750 nm during maturation (Brach *et al.* 1982).

Colour difference meters

Colour difference meters can be used to measure the chlorophyll content of fruits and vegetables (Medlicott *et al.* 1992, Meir *et al.* 1992). Chlorophyll content can vary during maturation and senescence of crops and therefore it might be possible to adapt this method in objectively measuring crop maturity. A colour difference meter (Minolta Chroma CR-200) was successfully used to measure the surface colour of peaches and relate this to fruit pigments, soluble solids content and firmness (Kim *et al.* 1993). The range of dominant wavelengths varied between peach cultivars but they were all within the range of 565–780 nm (Kim *et al.* 1993). A colour difference meter, Minolta Chroma CR-200 (Figure 8), was successfully used to measure the surface colour of peaches and relate this to fruit pigments, soluble solids content and firmness (Kim *et al.* 1993). Colour difference meters measure various properties of colour expressed as L^* , a^* and b^* .

Heat units

Day degrees or heat units are used to compute harvest dates for vining peas and predict maturity dates for cauliflower and broccoli (John Love, personal communication).



Figure 8 A colour difference meter being used to measure the colour of melons at Cranfield University in the United Kingdom. (Source: A.J. Hilton. Reproduced with permission of Cranfield University.)

Acoustic and vibration tests

The sound of a fruit as it is tapped sharply with the knuckle of the finger can change during maturation and ripening. Consumers sometimes use this method of testing when purchasing fruit. Fruits such as melons may be tapped in the field to judge whether they are ready to be harvested. This method may also be used postharvest to determine their maturity, for example in pineapples. The principle of the method has been applied in equipment that puts vibration energy into a fruit and measures the response of the fruit to this input (Figure 9). Although much of this work is in the experimental stage, good correlations

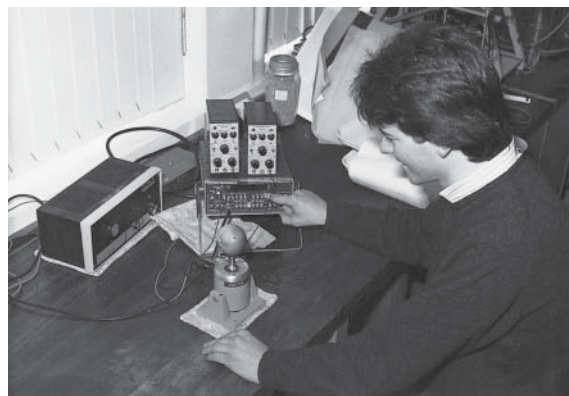


Figure 9 Equipment which puts vibrational energy into fruit and measures its response being tested on apples at Cranfield University. (Source: A.J. Hilton. Reproduced with permission of Cranfield University.)

have been found using the second resonant frequency to determine the maturity of apple, tomato, mango and avocado (Darko 1984, Punchoo 1988). The following formula was used based on the work of Cooke (1970):

$$f_2^2 \cdot m^{2/3}$$

where:

f_2 = the second resonant frequency

m = the mass of the fruit.

Commercial audio speakers have been used as vibration exciters with the response of the fruit (Mutsu apples and Nijitsu-seiki pears) measured on a computer-controlled strain gauge. During storage for 20 days it was found that the resonance frequency shifted from 110 to 80 Hz suggesting that the method was measuring some quality change (Ikeda 1986). Velocity of propagation of mechanical pulses through whole apple fruits can be used to provide a non-destructive method of monitoring changes in the elastic properties of the tissue (Garrett and Furry 1974). These elastic properties may be related to the degree of fruit maturity and other characteristics such as fruit firmness and toughness (Garrett and Furry 1974). Self *et al.* (1993) have shown that there is a relationship between ultrasonic velocity and the maturity and ripeness of bananas, the ripeness of avocados and perhaps the internal browning in pineapples. Mechanical resonance techniques have been applied to apples and tomatoes (de Baerdemaeker 1989). The second resonant frequency in apples was shown to reduce with ripeness, with 600–750 Hz for non-attractive unripe fruits to 200–500 Hz for not attractive, over ripe fruit. Attractive, ripe fruit were in the frequency range of 400–600 Hz. Similar results were shown for the stiffness factor. The stiffness factor in tomatoes was also shown to decrease during storage. Equipment developed by de Baerdemaeker at the Katholieke Universiteit in Leuven in Belgium uses a small microphone mounted in a piece of plastic pipe containing shaped polystyrene on which the fruit is placed about a centimetre from the microphone. The fruit is tapped lightly with a small object (a pencil will do) on the side of the fruit opposite to the microphone, and the first resonant frequency, picked up by the microphone, is measured. The measurement was found to change with the changes in fruit ripeness.

Measurements of acoustic responses of apples were tested against human auditory sensing and found to correlate well in the first and second resonant frequencies (Chen *et al.* 1992). In Japan this technique, based on acoustic impulse responses, has been developed and installed in commercial packing facilities (Kouno *et al.* 1993c). It is being used for watermelons to detect both the ripeness and any hollowness in the fruit. Nine machines have been installed and they are as accurate in grading melons as skilled inspectors using 'the traditional slapping method'. Kouno *et al.* (1993b) described their ripeness and hollowness detector that was called MWA-9002.

A sensor system for automatic non-destructive sorting of firm (tree-ripe) avocado fruits used vibrational excitement of one side of the fruit, while measuring the transmitted vibration energy on the other. Special signal processing hardware and software were developed for computing several alternative firmness indexes, which were highly correlated with value obtained by the standard destructive piercing force test method. Optimal classification algorithms were developed whereby fruit could be classified into two or three firmness grades (Peleg *et al.* 1990).

While success has been shown with these methods, it is not always clear exactly what characteristic or group of characteristics of the fruit is being measured. Good correlation was shown between weight loss of fruit and changes in resonant frequency in apples (Ghafir and Thompson 1994a, 1994b). Terwongworkule (1995) showed that stiffness coefficient was related to weight loss in stored apples in that where the fruit were stored at high humidity the stiffness coefficient remained constant and when they were stored at low humidity it reduced in proportion to weight loss. It appears therefore that stiffness coefficient in apples is related to their moisture content or some related factor and would not be of use in measuring its maturity or ripeness.

Acoustic response measurements gave a reliable indication of the change in mechanical properties of fruit including fruit maturity and ripeness as well as water status, which was not detectable by conventional firmness measurements. Duprat *et al.* (1997) compared penetrometer measurements of firmness of Golden Delicious apples with an acoustic impulse method during 8 months of storage at 1 °C and 96% r.h. They found that the penetrometer measurements provided better discrimination between

immature fruit, while the acoustic impulse response measurements were superior for ripe fruit. Tu *et al.* (2000) also used acoustic non-destructive measurements for changes in firmness of apples. Yurtlu (2012) compared a lateral impact test, low mass impact methods and acoustic impulse response and with a Magness and Taylor penetrometer on peaches. The best correlation of the data was found between modulus of elasticity and the non-destructive lateral impact parameter. The highest correlation in all parameters was found between low mass impact methods. Shmulevich *et al.* (2003) demonstrated the advantage of measuring avocado fruit by a low-mass impact technique compared to the acoustic technique.

Electrical properties

Studies have been carried out passing electrical currents through fruit. Some correlations have been shown between different characteristics of the fruit, some of which are related to fruit ripening, and the way the current passes through the fruit (Nelson 1983, Kagy 1989). Koto (1987) found a difference in electrical properties between fresh fruit and those that were spoiled or physically damaged. He showed that capacitance of deteriorated cells increased while resistance would decrease, and therefore these measurements could be used to determine the freshness or age of the fruit. McLendon and Brown (1971) also found that the dielectric properties (resistivity and conductivity) of peaches changed with fruit ripeness. At 500 Hz the dielectric constant of green peaches was 550 while for ripe peaches it was 150. At 5000 Hz the figures were 300 and 100, respectively. These figures appear to be high because the dielectric constant of water under these conditions is 80 and grain 4 (B.C. Stenning, personal communication). In watermelons specific electrical resistance appeared to decrease with increasing sugar content (Nagai 1975). In work on honeydew melons Kagy (1989) found no significant relationship between capacitance, loss tangent and resistance and weight loss firmness and sugar content. The measurement of electrical impedance of Granny Smith apples after impact tests showed good correlation with bruise levels, with no significant changes in the impedance properties of the fruit after the initial damage had occurred (Cox *et al.* 1993). These electrical properties are exploited widely in the measurement of moisture content of low moisture

products (Dull 1986), but there are no publications to indicate that the method has been sufficiently developed for use in determining maturity of fruits and vegetables.

Electromagnetic

Nuclear magnetic resonance (NMR) spectroscopy has been developed in human pathology to provide real time images of the inside of the body. It can be used for detecting protons and the variation and binding state on water and oil. Such equipment can be used to provide similar micro-images of the internal structures of fruits (Williams *et al.* 1992). NMR has also been shown to correlate well with sugar content of bananas and apples (Cho and Krutz 1989) and oil content in avocados (McCarthy *et al.* 1989). The technique of using a surface coil NMR probe to obtain the oil/water resonance peak ratio of the signal from a region of an intact avocado fruit produced the best result and has desirable features for high-speed sorting (Chen *et al.* 1993). NMR was also shown to be effective in detecting the physiological disorder, water core, in apples (Wang *et al.* 1988). Magnetic resonance imaging has been used to obtain images of bruises on apples, peaches, pears and onions, pits in olives and prunes and insect damage in pears (Chen *et al.* 1989). Shewfelt and Prussia (1993) pointed out that its cost and speed of operation limit the great potential of magnetic resonance imaging. Williamson (1993) acquired three-dimensional data sets from using NMR microscopy with a high field spectrometer (7.2 T; 300 MHz), and with surface rendering techniques was able to display the spatial arrangement of seeds and vascular tissue of soft fruit.

Near-infrared reflectance

Near-infrared reflectance (NIR) can be used for measuring moisture content using light-emitting diodes. These operate at water-absorbing wavelengths, which may find application in rapid on-line determination of soil moisture, milk and feed composition (Cox 1988). An NIR spectrum analyser has also successfully been used to test the taste of rice and results correlated well ($r=0.926$) with results from a taste panel (Hosaka 1987). NIR has been studied in relation to measuring the internal qualities of fruit. Correlations between sugar content of apples, peaches,

pineapples and mangoes and NIR measurement have been shown (Kouno *et al.* 1993a). NIR measurement was achieved, using a Nireco model 6500 near-infrared spectrophotometer, by placing the fruit so that the light beam on the surface was at right angles to the fruit surface and covered with a black cloth to avoid the influence of external light. Four places around the equator of the fruit were selected and the NIR beam was irradiated at 2 nm intervals from 400 to 2500 nm onto the fruit and the average absorbance was measured (Kouno *et al.* 1993b). Fruit firmness, acidity and soluble solids content were measured directly afterwards on the same fruit, and adequate correlations were shown between the NIR measurement and soluble solids content for both mangoes (multiple regression coefficient of 0.954) and pineapples (multiple regression coefficient of 0.825). Results for acidity and firmness were also encouraging for mangoes that had a multiple regression coefficient of 0.856 for acidity, 0.949 for the firmness of the unpeeled fruit and 0.920 for the peeled fruit. For pineapples the multiple regression coefficients were 0.686 for acidity, 0.460 for firmness of unpeeled fruit and 0.568 for peeled fruit (Kouno *et al.* 1993b). Near-infrared techniques have been used in the measurement of moisture content in crops (Williams and Norris 1987) and have been shown to be able to measure sugar content of fruit non-destructively (Chen and Sun 1991). NIR spectral data gave good correlations with nitrogen and calcium concentrations of pear fruit peel. It may therefore be possible to obtain information on the actual percentage of fruits with undesirable mineral concentrations, and non-destructively segregate desirable and undesirable fruits before they are placed into store (Righetti and Curtis 1989). Peirs *et al.* (2000) showed for Jonagold, Golden Delicious, Elstar, Cox's Orange Pippin and Boskoop apples that it is possible to use NIR spectroscopy as a non-destructive technique for measuring internal apple quality. Saranwong *et al.* (n.d.) used dry matter as harvesting indices for hard green mangoes and developed NIR calibration equations that were sufficiently precise for determining dry matter and starch of hard green mangoes. Ripe mangoes would have excellent eating quality and high TSS if the fruit contained sufficient amounts of dry matter and starch at harvest date. They found that the TSS of ripe mangoes could be precisely predicted from the dry matter and starch

measured non-destructively with NIR at harvest. NIR was also shown to have the capability of measuring TSS and DM in the ripe mango cultivar Caraboa (Saranwong *et al.* 2003). Lu *et al.* (2000a, 2000b) evaluated the potential of NIR diffuse reflectance between 800 and 1700 nm for determining the firmness (compared to a Magness and Taylor firmness test) and sugar content of Empire, Golden Delicious and Red Delicious apples. From the data they developed statistical models using principal component analysis/regression. Improved predictions were obtained when NIR reflectance was correlated with the slope of the Magness and Taylor force-deformation curves. NIR reflectance also showed good correlation TSS content in peeled apples. This was confirmed by Park *et al.* (2003) who used diffuse reflectance measurement between 400 and 1800 nm regions of the spectrum on the apple cultivars Gala and Red Delicious. They compared them with TSS and firmness by the Magness and Taylor penetrometer and showed good correlations with principal component regression and Mahalanobis distance analysis.

Radiation

Both X-rays and γ -rays have been used to assess quality and maturity characteristics of fresh produce. A lettuce harvester was developed which used X-rays to determine which heads were sufficiently mature for harvesting (Lenker and Adrian 1971). Garrett and Talley (1970) used γ -rays for the same purpose. The basis of these tests depends on the rate of transmission of the rays through the lettuce, since this depends on the density of the head that increases as the lettuce matures. X-rays can also be used to detect internal disorders of crops such as hollow heart in potatoes Finney and Norris (1973), split pit in peaches (Bowers *et al.* 1988) and granulation in oranges (Johnson 1985). X-rays were used in prototype potato harvesters to differentiate between the tubers and extraneous matter such as clods of earth and stones (Whitney 1993). The equipment was mounted behind the chain lifter, but was found to be impractical because the height of fall of the tubers was too great. Butz *et al.* (2005) describe terahertz radiation (T-rays) that is in the far-infrared region. Unlike X-rays, T-rays are not harmful, so there are no exposure worries. They commented that they were not being used at that time on fruit and vegetable

but non-invasive food applications were possible e.g. determination of the ripeness of tomatoes.

Physiological

For fruit, which pass through a distinct climacteric rise in respiration during ripening, it may be possible to sample the fruit, keep it at a relatively high temperature (for apples in Britain a temperature of about 20 °C would be appropriate) and measure its respiration rate. By doing this it may be possible to predict the number of days the fruit would have taken if left on the tree to commence the climacteric rise. Respiration rate is calculated by measuring their uptake of oxygen or the output from the fruit of such gases as carbon dioxide, ethylene or other organic volatile

compounds associated with ripening. Recasens *et al.* (1989) measured the concentration of ethylene in the core of apples at different times during maturation and found that for many cultivars the commercial harvest date was 10–15 days after the initiation of the ethylene increase. However, there are problems of applying this method in practice. Testoni and Eccher Zerbini (1989) found high variability in the ethylene content between fruits and also poor correlation between internal ethylene and other maturity indices such as skin colour, firmness, TA and soluble solids. In previous studies on the respiration rate of apples it was found that for the cultivars studied, which were Cortland, Delicious, Golden Delicious and McIntosh, there was no definite point on the climacteric curve associated with harvest date (Blanpied 1960).

3

Harvesting and handling methods

This chapter deals with the ways that crops are removed from their parent plant and transported from the field. The method used should take into account:

- the delicacy of the crop;
- the importance of speed during and directly after harvesting;
- the economy of labour in the operation;
- the need for the harvesting method to fulfil the market requirements.

Crop damage

Where harvesting and handling operations are not carried out with sufficient care and attention, damage can be done to the crop that may have repercussions during subsequent marketing and storage operations. These include:

- shortening of the potential maximum crop storage life due to increased respiration or ethylene biosynthesis;
- increased levels of microorganism infection through damaged areas;
- increases in some physiological disorders.

The types of injury that can be inflicted on the crop include cuts, scuffs and bruises. Compression, impact or vibration can cause bruises.

Ragni (1997) showed that in Italy most defects to apples were caused during harvesting and transport to the packhouse, rather than by maltreatment during grading and packaging. It was found that the grading and weighing/packaging machines did not cause damage to the fruits to a level that would be noticed by the consumer. However, overturning the boxes of fruits could cause bruising of the pulp, noticeable by the consumers. Jarimopas and Therdwongworakul (1994) found that mechanical damage to mangoes due to the washing machine only and the combination of washing and disease control machines were 0.6 and 1.5% respectively. Only 0.4% of control mangoes were damaged. The washing machine consisted of a rolling conveyor with sprayers and brushes. The disease control machine was a 360-L steel bin with rotating plates to submerge mangoes in 500 μL^{-1} benomyl solution, at 55 °C for 5 min. Peaches suffered the most severe impacts when dropping on to belt conveyors, into the bottom of bins and being placed manually on rotating surfaces (Ragni *et al.* 2001). Damage caused by three falls of different peach cultivars was compared and Rich May showed 29% damage, Big Top 24%, Ruby Rich 15% and Flaminia only 5%.

Various inexpensive devices could minimize impact damage, such as the use of chutes to avoid fruit falling on to a belt conveyor immediately above a support bar and the use of soft plastic 'cushions' at

the bottom of bins. The use of such devices would allow some fruit such as peaches to be picked at a riper stage and so enhance the flavour (Ragni *et al.* 2001).

Cuts

These are self-explanatory where the crop has come into contact with a sharp object, which can penetrate its surface. They can be inflicted where knives are used during harvesting or in opening boxes of packed fruits or vegetables. Also they have been observed in badly made nailed wooded field boxes or inappropriately stapled fibreboard cartons. It is also important that harvests should have short fingernails.

Scuffing

This occurs when fruits or vegetables are caused to move across a hard, usually rough, surface so that their cuticle and layers of cells are scraped away by abrasion. In comparisons with different types of postharvest damage inflicted on citrus fruits Tariq (1999) found that scuffing caused the greatest reduction in postharvest life.

Compression bruising

Where the downward force on the crop is above a threshold level, it can be bruised. This damage may also be a function of time, especially where the pressure is close to the threshold value. It may be as a result of overfilling boxes and then stacking the boxes so that the crop in the lower boxes supports the weight. It is also commonly found in the lower layers of potatoes and onions in bulk stores. In any species of crop there may be differences between cultivars in their susceptibility to compression damage. It may also be related to their moisture content; the higher their moisture content is, the more they are susceptible, which may be related to preharvest cultural effects. Compared to bulk storage, box storage reduced the average weight loss of stored potatoes by 16%, the average quality index of subcutaneous tissue discoloration by 30% and the percentage of pressure spots with a depth greater than 1.5 mm by a factor 15 (Scheer *et al.* 2000). Hironaka *et al.* (2001) applied a static load of 196 N (20 kg force) to the potato cultivar Norin-ichigo during storage at 7 °C for 60 days.

They found that static loading increased the glucose, fructose and reducing sugar contents, as well as the invertase activity during storage.

To overcome the problem it may be necessary to redesign boxes or ensure that they are not over-filled. In crops that are bulk stored a certain level of compression bruising may be accepted to maximize the capacity of the stores for economic reasons.

Impact bruising

This results from either the crop being dropped or something hitting it. The damage might be obvious on the surface of the crop or it might be internal. Internal blackening of potatoes is a common form of this latter effect, which is temperature sensitive and occurs more frequently when the tuber temperature is below 8 °C or above 20 °C (John Love, personal communication). Even when the crop is protected within a fibreboard box, impact damage can occur if the box is dropped or in it is over-filled. Work carried out on onion bulbs showed that if they were dropped on to a hard surface, they could be damaged even if the fall was as little as 30 cm (Thompson *et al.* 1972a, 1972b). In a study of handling of yams (Thompson 1972a, 1972b) it was shown that subjecting the tubers to impacts commonly experienced during handling resulted in greatly increased losses during subsequent storage. The contribution to the total amount of subcutaneous tissue discoloration in potatoes was 16% for harvesting through bin-filling, 22% for storage, 27% for shovelling through truck loading and 35% for truck unloading through packaging (Scheer *et al.* 2000).

Mexican exports of Hass avocados to European and Japanese markets are affected by the presence of dark spots on the fruit caused by the fungus *Colletotrichum gloeosporioides* and also as a consequence of bruising during harvest and postharvest (Zamora-Magdaleno *et al.* 2001). The dark spots were associated with oxidation of polyphenols deposited in the cell walls of the dead cells and in intercellular spaces.

Bruised and non-bruised tomato fruit were placed individually inside the electronic nose-sampling vessel, and the 12 conducting polymer sensors were lowered into the vessel and exposed to the volatile given off by the fruit. The electronic nose proved to be a useful tool to non-destructively identify and classify tomato fruit exposed to mechanical injuries (Moretti

et al. 2000). To avoid impact damage crops must be handled with great care. This is particularly the case where they are harvested and handled mechanically. Shutes and cushioned pads should be used to break the fall of the crop and distances of fall should be kept to a minimum.

Vibration bruising

This occurs when crops are being transported, especially in lorries. It is common where crops are packed loosely in the lorry or even in boxes and is largely the result of the crop moving and impacting on each other or the walls of the lorry or box. It can result in an increase in the respiration rate of the crop as well as surface bruising. To minimize the effect the crop needs to be packed tightly to reduce its movement. Equipment is available in packhouses to 'tight fill' boxes. Internal dividers can be used on accurately size-graded produce to reduce mutual impacts. To reduce vibration injury specially sprung lorries can be used for transporting soft fruit or bubble polyethylene film liners at the bottom of crates are used for grapes (John Love, personal communication). Ragni *et al.* (2001) showed that in trays of peaches vibrations were more intense at the top of a stack than in those at the bottom.

Harvesting

Harvesting operations are frequently carried out in traditional ways by hand, but machines and even chemical sprays are used as aids or methods to speed the harvesting and field handling operations.

Hand harvesting of fruits

For soft fruit such as strawberries and raspberries, which are borne on low growing plants, harvesting is carried out by breaking the fruit stalk and putting them into a suitable container (Figure 10). This may be the box or punnet into which the fruit is to be taken directly to market or they may be placed into a container that is taken to a packing centre for grading and transfer to a consumer pack. A bag that fits over the hand can help to speed picking and reduce damage to these delicate fruit (Figure 11).

Fruits that are borne on trees, such as apples, mangoes, citrus fruits and avocados, are more difficult



Figure 10 A mechanical harvester being used for strawberries for processing. (Source: H.D. Tindall.)



Figure 11 Harvesting aid for soft fruit.

to harvest. Traditionally the harvester would carry a ladder and use that to reach the fruit. This is very time consuming and various ways have been developed to speed up the operation. A long pole with a bag at the end together with some device for cutting or breaking the fruit stalk is commonly used (Figures 12 and 107). Picking platforms are available which enable the harvester to be towed around the orchard from tree to tree so the platform can be raised and lowered enabling the fruit to be picked (Figure 13). The way in which the fruit is actually removed from the tree can be important. An example of this is that in California grapefruit are cut from the tree using clippers that is assumed to reduce fungal infections while in Florida they are harvested by twisting and pulling the fruit to break the fruit stalk where it has been shown that there is a higher incidence of rotting when fruit stalks

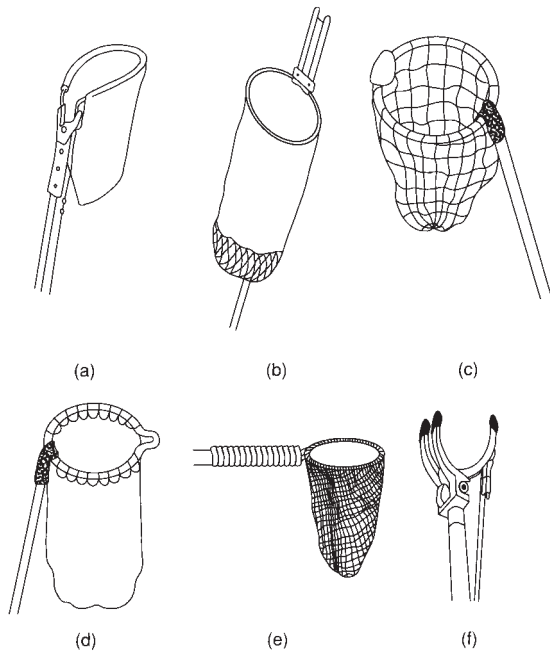


Figure 12 (a–f) Fitments used on picking poles to facilitate fruit harvesting on tall trees.

are cut. This effect was shown for papaya where fruits harvested by cutting the fruit stalk had a lower incidence of rotting during subsequent storage than fruit harvested by twisting and pulling it from the plant (Thompson and Lee 1971).

Hand harvesting of vegetables

Low growing vegetables are harvested in the same way as that described for low growing fruit. With root crops these must often be dug from the soil, usually by inserting a garden fork, or other similar tool, below the crop and prising it upwards. Other root crops such as beetroot and radish can be pulled from the soil. Great care must be exercised to ensure that the tool is well below the crop so that it is not damaged.

Mechanically harvesting of fruit

Very little fruit destined for the fresh market is harvested by machines because the damage likely to be caused to them could result in rapid deterioration in quality during the marketing chain. Zamora-Magdaleno *et al.* (2001) found that damage



Figure 13 A platform used to facilitate fruit harvesting from tall trees.

to avocados was more likely when crops are harvested mechanically. Fruit destined for processing may be harvested mechanically; however, it is usually important to process it very soon after harvesting otherwise they can deteriorate. Oranges for juice extraction may be removed from the trees by powerful wind machines being dragged through the orchard followed by a device for collecting them from the ground. The grass beneath the trees is usually mown before harvesting, and these devices usually have nylon brushes that sweep up the fruit and transfer it to containers. However, they will also collect other things on the surface of the grass, which can be a problem if sheep have been grazed in the orchard. Tree shakers can also be used, which are attached to the tree trunk and violently shake the tree to dislodge the fruit. Canvas sheets mounted on a frame may be placed beneath the tree to break the fall of the fruit and thus reduce damage levels. The canvas slopes away from the tree so that the fruit rolls gently away preventing bruising caused by other fruit

falling from the tree. These 'shake and catch' methods of harvesting can result in considerable damage to fruits. Miller *et al.* (1973) reported a damage level of 51% for Golden Delicious, and Berlage and Langmo (1979) reported a damage level of 64%. These fruit were grown on standard trees, and the damage level was assessed as fruits not conforming to the 'Extra Fancy' grade.

In order to reduce the difficulty of dislodging the fruit from the tree, chemical sprays have been recommended. These encourage the formation of the natural abscission layer on the fruit stalk and should be applied a few days prior to harvesting. Ethrel, abscisic acid and cycloheximide have all been shown to be effective but are not permitted for use in all countries. Hitchcock (1973) showed the effectiveness of Ethrel treatment on gooseberries and the importance of concentration (Figure 14). In practical use fruit maturity and weather conditions affected the time between application of Ethrel and fruit fall. Ethrel can reduce the shelf life of fruits and is not allowed by some supermarkets especially on tomatoes (John Love, 1994, personal communication). Grapes and

soft fruits for processing, such as blackcurrants, may be harvested by tractor-mounted machines which have combing fingers which are run up the stems pulling off the fruit bunches, as well as a high proportion of the leaves (Figure 15). The fruit are removed from the plants using small amplitude high frequency vibration by the rubber fingers being mounted on a vertical drum that rotates at the same velocity as the harvester moves forward. The fruit may subsequently be separated from the leaves by blowers and the juice extracted. In other cases the fruit is taken straight from the field and passed through a press and filter system. An important factor to be considered with mechanical harvesting is to breed cultivars whose fruit all mature at the same time. Work on the development of mechanical harvesters for strawberries was carried out at Silsoe College (Hitchcock 1973, Williams 1975) where the berries were detached by tensile force with a shaker unit and collected on a sledge. With these mechanical harvesters for strawberries (Figure 10) and raspberries (Figures 16 and 17) the harvested fruit needs to be graded before it is processed or marketed.

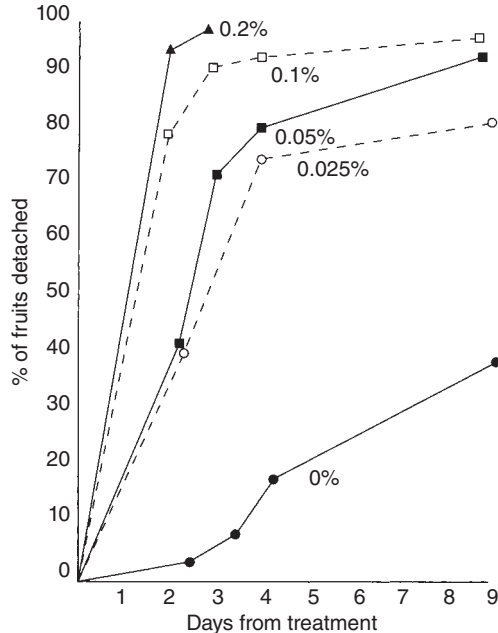


Figure 14 Percentage of fruit detached from Careless gooseberries 9 days after the application of various concentrations of Ethrel. (Source: Hitchcock 1973. Reproduced with permission of Cranfield University.)

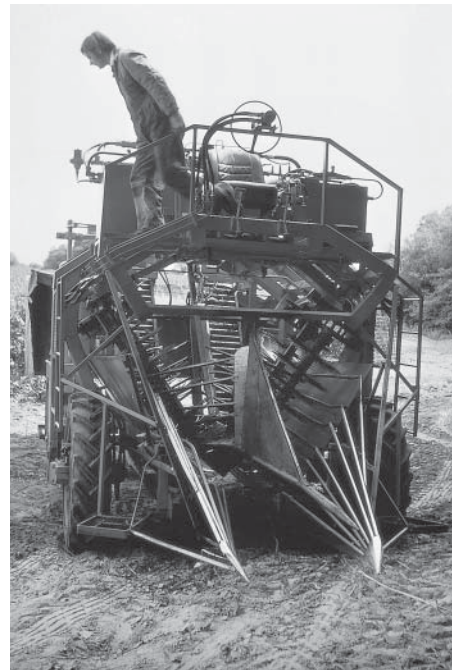


Figure 15 Mechanical harvester used for blackcurrants for processing into juice in the United Kingdom. (Source: H.D. Tindall.)



Figure 16 Raspberry harvester in operation in the United Kingdom. (Source: H.D. Tindall.)

Fruit trees or bushes can be specially trained to facilitate mechanical harvesting. Problems with raspberry harvesters is that fruit matures over a period of 20–40 days and requires 5–10 pickings or more if each fruit is to be picked in prime condition (Ramsey 1985). To overcome this problem a machine was developed in Scotland that shook the canes at such a frequency that only the ripe fruit fell off. This was coupled with an effective catching device. Apple trees grown on a hedgerow system could be harvested with combing fingers giving 85% Grade 1 fruit, although a significant proportion of the fruit remained on the trees (LeFlufy 1983).

In the meadow orchard system of growing apples, peaches, babaco and guavas, the whole of the tree is harvested just above the ground each year or every other year. The fruit are then separated from the stems in machines in the packhouse (Mohammed *et al.* 1984). Using this method trees are planted very close together with densities in the order of 10,000 trees per hectare compared to conventional densities of 87–125 trees per hectare (Alper *et al.* 1980). Van Oosten (1986) discussed the possibility of planting



Figure 17 Field grading of mechanically harvested raspberries in the United Kingdom. (Source: H.D. Tindall.)

babaco at 1×1.25 m giving 8000 plants per hectare and a potential yield of $320 \text{ tonnes ha}^{-1}$.

Other planting and training methods for tree to facilitate mechanical harvesting have been described, including the Lincoln Canopy that was developed in New Zealand. Trees were spaced 3×4.5 m and the trees are trained on wires supported on T frames (1.5 m high $\times$ 2.4 m wide $\times$ 15 m apart). The fruits are detached from these trees by a lightweight impactor located below the canopy that strikes upwards while advancing between each stroke. The detached fruit are caught on a polyethylene-padded conveyor (Diener and Fridley 1983).

Salih and Ruhni (1993) described a prototype hand-held mango harvester. It consisted of an adaptation of the commonly used pole with a bag attached. The new design had a cutter bar attached at the end of

the pole above the bag that was operated from a small electric motor powered by a 12-v battery.

Mechanical harvesting of vegetables

Mechanical aids to harvest vegetables such as lettuce, cauliflowers and cabbages involve cutting the vegetable by hand and placing it on a conveyer on a mobile packing station that is slowly conveyed across the field (Figure 18). The vegetables are packed on site and transferred to a vehicle for direct transport to a precooler or directly to market (Figure 19). Tissue damage during harvesting can stimulate enzymatic action resulting in the production of off-flavours, so they should be processed as quickly as possible after harvest. Mechanical harvesting of green beans may lead to discoloration of the broken ends



Figure 18 Tractor-mounted conveyor belt to facilitate hand harvesting with a trailer used for field packing.



Figure 19 Details of the trailer used for field packing cauliflowers.

of the beans, especially if there is a delay in processing them (Sistrunk *et al.* 1989). Brussels sprout harvesters have been developed, which perform similar operations to pea viners; harvesting the whole plant and cutting the sprouts from the stems. In both these cases special processing cultivars have been bred where all the pea pods or Brussels sprouts mature at exactly the same time. Brussels sprouts may be stopped to ensure more uniform development (John Love, 1994, personal communication). In root crops mechanized harvesters remove the crop from the ground by either undercutting it or, in the case of some potato harvesters, inverting soil the ridges in which the crop is grown. Mouldboard plough sub-soilers and other tillage tools used in root crop harvesting may require a lot of power to remove them from the soil. Using vibrating digger blades can reduce the power required, which varies with the amplitude of the vibration (Kang *et al.* 1993). Digger blade performance was better in separating tubers from the soil with high amplitude vibration, and tractor traction was insufficient at low amplitudes.

Field transport

After the crop has been removed from the plant it is taken to market, a packhouse or a store. Various systems and packing materials have been developed for this purpose. The selection of type and design is related to protection of the produce, convenience of handling and cost effectiveness. Sometimes the crop is harvested into one type of container and is then transferred to another type for transport from the field. An example is the picking boxes used for apples that are worn around the harvester's neck. Fruit may be transferred from these boxes to a pallet box to be taken and stacked in the storage chamber. Types of package and the material from which they are made vary considerably.

Bananas are particularly delicate and easily damaged fruit. Exposure of harvested bananas to carelessness during loading, unloading and overloading, insufficient and poor cushioning, and poor truck suspension systems and road conditions seem to be the factors causing physical damage and stress in the Philippines (Alvindia *et al.* 2000). Transporting bananas to the packhouse has been the subject of

considerable research. Overhead cableways, specially padded boxes and padded trailers have all been used. Thompson and Lee (1971) showed that packing papaya fruit in specially padded boxes for field transport reduced postharvest losses compared to traditional methods. Grapes are transported from the field in various ways. Zoffoli and Latorre (2011) described the operations in Chile where fruit are harvested and placed into picking boxes containing 18–20 kg of fruit and taken to a temperature-controlled packhouse. The fruit are placed on a conveyor belt and trimmed and packed into the boxes that will be used for marketing. An alternative method is where the fruit are harvested in the field placed directly into the boxes used for marketing. They commented that this method has reduced water loss and bruising, presumably by the lower amount of handling the grapes.

Mencarelli *et al.* (2005) found that the most important requirements of grape transport were firstly that bunches must be immobilized within a container. They should also be cushioned against impact and not over-filled. Fruit that are to be stored may be loaded into pallet boxes in the field, e.g. apples and potatoes. These are loaded with a front-end loader onto trailers and taken directly to the store.

Where vegetables are mechanically harvested e.g. potatoes and onions, integrated systems are often used, and the crop is harvested and loaded directly into a trailer for transport to the store or packhouse. In some cases consumer packs are filled in the field and directly loaded onto a lorry for transport. Bulk transport is also used for transporting some fruit e.g. oranges and grapes where they are taken directly to a processing plant.

4

Precooling

To achieve maximum storage life for many crops or to reduce losses during their marketable life it is essential to keep them at the most appropriate temperature, which is usually just above that which will cause chilling or freezing injury. Chilling injury is where crops develop temperature associated physiological disorders or abnormalities when exposed to temperatures above those which would cause them to freeze. They may not produce symptoms until the crop is exposed to higher temperatures. Chilling injury may be apparent as:

- failure to ripen in climacteric fruit
- different forms of external abnormalities
- internal discoloration
- predisposition to microbial infection.

Crop susceptibility to chilling injury is influenced by such factors as exposure time, crop cultivar and the conditions in which the crop was grown. Intermittent warming and temperature preconditioning have been shown to reduce the effects of chilling injury in certain crops (Wang 1982). The exact mechanism by which chilling injury affects the crop has still not been fully determined. It has been shown to be concerned with loss of membrane integrity and ion leakage from cells and changes in enzyme activity (Wang 1982) but exactly why some crops are susceptible and some resistant is still a major research topic. Freezing injury, on the other hand, is caused when ice crystals

form within the cells of fruits and vegetables. Since these cells contain soluble material the freezing temperature is below the freezing point of pure water at normal pressure, that is lower than 0°C. Freezing injury can occur at temperatures at which the cells will freeze because, according to Burton (1982), initial ice formation will be in the more dilute liquid on the surface of the cell walls.

To maximize the effect of precooling the crop should be brought to the optimum temperature as quickly as possible after harvest. Precooling is not always necessary since some crops are not very perishable, and rapid cooling would make no difference to their marketable condition or storage life. In many cases, such as curing root crops, drying onions and quailing oranges, there are definite storage advantages to exposing the crop to high temperature after harvest and not cooling them quickly. Also for some crops precooling would be too expensive and therefore not cost effective. In Brazil Menezes *et al.* (1998) exposed two melon hybrid cultivars, Gold Mine and Agroflore 646, to solar radiation for 0, 1, 2, 3 or 4 h between 10.00 and 15.00 h directly after harvest and noted the effect on subsequent storage. They found that leaving harvested fruits in the sun for those periods had no effects on quality or storage life. Precooling always needs to be combined with a cold chain, which means that they are transferred to storage at the optimum temperature directly after precooling.

Lallu and Webb (1997) found that for kiwifruit it was more economical to construct a cool store with cooling capability than to combine a precooler with a holding store. The establishment cost of a cool store with cooling capability was approximately 40% less than the combination of a precooler and holding store.

Heat removal

The rate of precooling of crops depends on:

- the difference in temperature between the crop and the cooling medium;
- accessibility of the cooling medium to the crop;
- the nature of the cooling medium;
- the velocity of the cooling medium;
- rate of transfer of heat from the crop to the cooling medium.

Heat can be removed from the crop in one of three ways:

- conduction
- convection
- radiation.

In precooling this is usually achieved by conduction that is the direct movement of heat from one object or substance to another by direct contact. If two objects or substances are touching and they are of different temperatures, heat will always move from the warmer to the cooler. If a crop has a relative large mass and a small surface area the crop will be cooled slower than if it had a smaller mass and or a larger surface area. This is because in the former the heat from the inside of the crop has to move to the surface of the crop before it is transferred. Precooling is a marketing asset for fresh fruit (Figure 20).

Exposing crops to the sun will heat them above the air temperature by radiation. This temperature increase can be over 10 °C (Rickard *et al.* 1978). If a crop is harvested in the early morning, it will be cooler since the sun has not warmed the air or the crop. The crop will also have a lower level of metabolic heat since, generally, the warmer the crop is, the higher will be its metabolic rate. Another factor that affects cooling is the packaging material used for the crop. If the cooling medium is air the boxes of produce should have ventilation holes that



Figure 20 Carton used for parsnip showing the emphasis on hydro-cooling. See colour plate section.

ensure good circulation through the crop. These holes may be placed to coincide with an air stream as in forced-air cooling. For hydrocooling and top icing the box used must withstand direct contact with water without disintegrating. Plastic boxes are suitable for this purpose or fibreboard cartons that have been waxed or treated with some other substance that will render them waterproof. Where heat is removed by evaporative cooling, as it is in vacuum precooling, then the crop must not be sealed in moisture-proof film such as polyethylene bags. If they are packed in bags then the bags must have adequate perforations to allow the water vapour to escape.

Generally the quicker the temperature is reduced after harvest, the longer will be the storage life of fruit and vegetables. However, precooling may increase the incidence of *Botrytis cinerea* stem-end rot, low temperature breakdown and physiological pitting, and Lallu (1997) concluded that it was preferable not to precool kiwifruits that are predisposed to these disorders. Phillips and Armstrong (1967) reported that rapid cooling after harvest can give peaches a stringy or woolly texture and therefore it was not recommended. Also certain fruit and vegetables benefit from exposure to relatively high temperature for curing before storage or even marketing.

Several methods of precooling are used commercially, and the selection of the most suitable method depends on the crop, the marketable or storage life required and the economics, that is the added value to the crop compared with the cost of precooling. Different methods include placing ice over the produce,

passing cold air around the produce, immersing them in water or reducing the air pressure around them. The different methods give widely different cooling times.

Precooling methods

Top icing

It has been used for many decades. Wardlaw (1937) recommended top icing using crushed ice made from fresh clean water. It is also called contact icing. It is commonly applied to boxes of produce by placing a layer of crushed ice directly on top of the crop. The ice melts and the cold water runs down through the crop and cools it. It can also be applied as ice slurry that is hosed onto the top of the crop from a tank. A typical slurry is made from 60% finely crushed ice, 40% water and usually with 0.1% sodium chloride to lower the melting point of the ice, although the water : ice ratios may vary from 1 : 1 to 1 : 4. Approximately 1 kg of ice was recommended for 1.8 kg of spinach leaves (Suslow and Cantwell 1999). Ice slurries give greater contact between product and ice, compared with top icing, and therefore should result in quicker cooling. The main use of top icing is for road transport and can be applied shortly after harvest, for example field-packed lettuce or broccoli, to begin precooling as the crop is harvested. Tindall (1983) reported that precooling with crushed ice might extend their storage life of peas from about a week to 15–20 days. Ragone (2011) found that breadfruit ripened in 1–3 days after harvest but their shelf life could be extended by precooling with chipped ice in the field and during transport. Wardlaw (1937) recommended top icing as soon as possible after harvesting for chicory and spinach. Lutz and Hardenburg (1968) found that top icing caused water spotting in okra and green beans.

Room cooling

This method simply involves placing the crop into a cold store. This may be the same cold store where the crop is to be stored for long periods or it may be to hold the crop before it enters the marketing chain to facilitate accumulation of sufficient produce to send to market. The type of room used for this may vary, but generally they consist of a refrigeration unit

across which cold air is passed from a fan. The air circulation may be such that the air is blown across the top of the room and falls through the crop by convection. It may also be blown in at the bottom of the store, in which case some type of plenum chamber is used. The drawback to these methods is the length of time it can take for the temperature of the crop to be reduced. The main advantage is its cost because no special facilities or equipment are required. Simple non-refrigerated rooms have been successfully used for precooling. These have advantages in that they can be erected and used in the field where no electricity is available. Examples of this method are evaporative coolers and tractor-mounted ice bank coolers.

Forced-air cooling

The principle of this type of precooling is to place the crop into the cold room but to arrange the airflow pattern so that it is forced directly through the crop. By doing this the heat given out from the surface of the crop is carried away in the stream of cold air thus setting up a temperature gradient, hence cooling the crop more quickly.

To achieve this rapid cooling the cooled air may be forced into a plenum chamber and the boxes of crops placed at exits to the plenum chamber. A common type of precooler that uses this method is the letterbox system. The plenum chamber takes up one wall of the cold store, with the wall of the chamber fitted with slots that are closed with removable covers. These slots coincide with pallet bases so that the cooled air is directed into the base. Horizontal exits from the base are blocked off, and the bases of the pallet are slatted so that the air is forced up through the base of the pallet and up through the produce and recycled back through the cooling unit (Figure 21).

A variation of this method is to have the plenum chamber set into the floor of the cold room so that when the produce is stacked in the cold room air is directed up through it. It is essential to ensure that as much air as possible is blown directly through the produce so all possible escape channels must be blocked off with dunnage or inflatable bags. It is also important to achieve even distribution of air through the crop to ensure uniform cooling. The speed at which the air is blown through the crop also affects cooling time. In a comparison between two airflow rates on the half cooling time of single apple fruits,

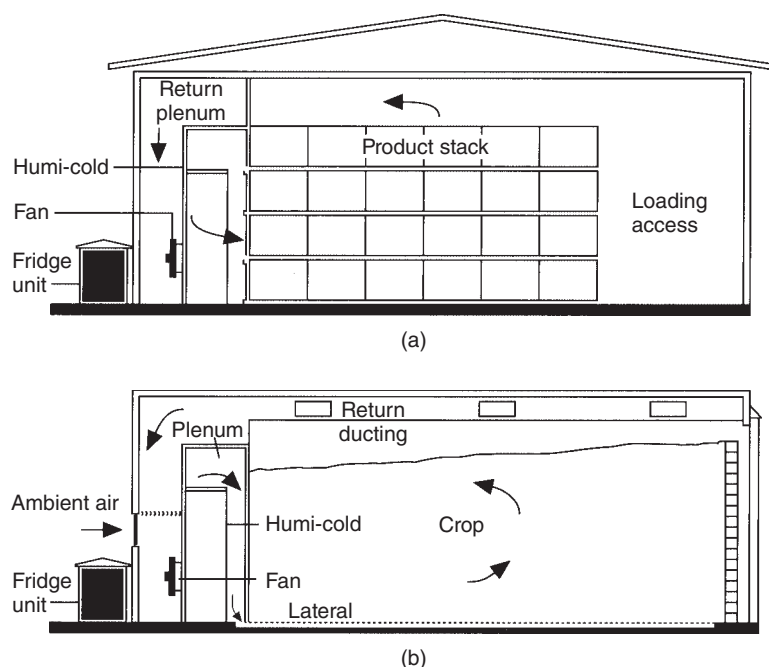


Figure 21 Forced-air high humidity precooler using (a) a letterbox ventilation system for produce stored in boxes and (b) for bulk stores. (Source: Positive Ventilation Limited, Yaxley, the United Kingdom.)

Hall (1972) found it to be 1.25 h in an air velocity of 40 m min^{-1} and 0.5 h at 400 m min^{-1} . Nelson (1978) reported that for grapes cooling must start as soon as possible and SO_2 applied within 12 h of harvest. Forced-air coolers were used in California that was designed to achieve $7/8$ cooling in less than 6 h. Holmes and Kemble (2009) recommended room cooling for oriental radishes grown in the southern USA. Turk (1989) recommended forced air at high humidity for figs.

An efficient forced-air cooling system can pass air through the crop of a very high velocity that can lead to desiccation of the crop. To reduce this effect various methods of humidifying the cooling air have been devised. One of these was the 'ice bank cooler' (Lindsey and Neale 1977, Neale *et al.* 1981). In conventional cold stores air is blown over cooling coils, which are metal pipes of various designs through which a cooled liquid is passed. Where rapid cooling is necessary the surface area of the pipes must be large and the temperature of the cooling liquid must be considerably lower than the air temperature to achieve good heat exchange. This can result in

moisture condensing or freezing on the surface of the coils, which reduces their efficiency, but perhaps even more important, it can increase the speed with which the crop is being desiccated. The ice bank cooler has the cooling coils immersed in water so that the water freezes building up ice around them. Water is then pumped over the ice and sprayed in a fine mist in a counter current of the air entering the plenum chamber. The air passes through a filter to take out liquid water particles from it and is then passed through the crop (Figure 22). The effect is that the air is both cooled and humidified. Humidity is close to 100% r.h. in a well-constructed system and will result in minimum desiccation of the crop during cooling. For precooling in Vietnam forced-air cooling, using an ice bank was recommended (Herregods *et al.* 1995). Elansari *et al.* (2000) described a wet deck precooling system for grapes used prior to refrigeration based on an ice bank.

Portable ice bank coolers have been constructed. These are small (about 1 tonne capacity) insulated trailers that can be towed into the field and driven from the power take-off of a tractor. The ice bank is

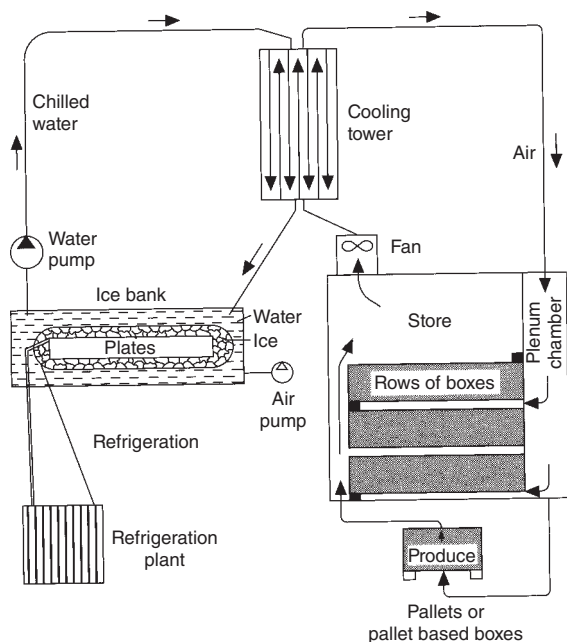


Figure 22 Schematic representation of an ice bank cooler. (Source: Neale *et al.* 1981.)

built up over night using the mains electricity, and the water pump and air circulation fan are driven from the engine of the tractor in the field. It is useful for crops such as strawberries where it may be important to begin cooling directly after harvest. Other systems have been developed to provide high velocity, high humidity air for rapid precooling. These have been marketed under trade names such as 'Humifresh', 'Humi-cold' and 'Airspray'.

Hydrocooling

The transmission of heat from a solid to a liquid is faster than the transmission of heat from a solid to a gas. Therefore cooling crops by contact with cooled water is much quicker than transfer of heat from the crop to air. Hydrocooling therefore can be very quick and result in no loss of weight of the crop during the precooling operation. If the crop is simply immersed in iced water, the water in direct contact with the crop will heat up and the rate of cooling will be slow. To achieve maximum effect the cooled water must constantly be passed over the crop. Submersing the crop in cold water that is constantly being circulated

through a heat exchanger can do this. Where crops are being transported around a packhouse in water, the transport water can also act as a hydrocooler.

A common design for a hydrocooler is to transport the crop on a perforated conveyer belt over a tank of water. Water is pumped from the tank over cooling coils, or blocks of ice, and allowed to fall on the crop and then through to the tank below. This system has the added advantage that the speed of the conveyer can be adjusted to the time required to cool the crop. Simple methods of hydrocooling have been developed to suit particular circumstances. For example in Thailand litchi fruits are harvested and packed in plastic boxes for export by refrigerated container to Singapore. Before loading them into the container they were dunked in ice water that cooled them slightly (Figure 23). Hydrocooling has the advantage over other precooling methods in that it can help clean the produce. However, the water can become contaminated with microorganisms that can result in increased levels of spoilage during subsequent storage or marketing. Chlorine may be added to the water if this is a problem.

Hydrocooling is unsuitable for many crops. Hydrocooling was very effective in capsicums (Figure 24) but they had a higher incidence of rots during subsequent storage than those that were not, even when chlorine was added to the water (Hughes *et al.* 1981). This was due to water being trapped between the fruit and the calyx. Cooling time depends on the size of the produce. Asparagus spears being long



Figure 23 Hydrocooling litchi in Thailand in preparation to loading for reefer container transport to Singapore. The fruit are in plastic trays and the bags contain ice to place in the hydrocooling water. See colour plate section.

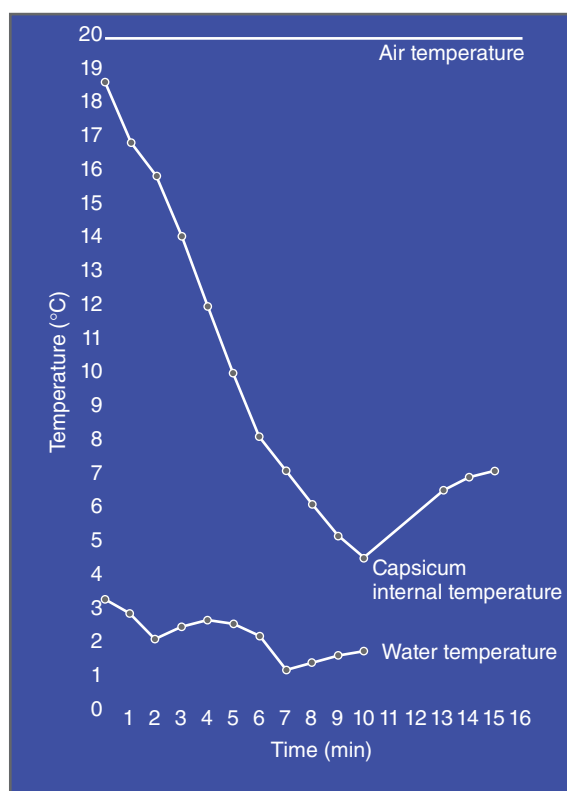


Figure 24 Changes in the internal temperature of capsicums during hydrocooling. (Source: Hughes *et al.* 1981.)

and narrow can be hydrocooled in some 2 min but capsicums, which are large and globular took about 10 min to cool. Tomatoes, melons and leafy vegetables are among the crops that can be successfully hydrocooled. With Kesar mangoes Kapse and Katrodia (1997) found lower weight loss and firmer fruits during storage after being hydrocooled to 12 °C compared with fruits hydrocooled to 16 °C or non-hydrocooled fruits. Stem-end rot caused by *Botryodiplodia theobromae* and anthracnose caused by *Colletotrichum gloeosporioides* did not occur for up to 13 days of storage when fruits had been precooled. The longest mean shelf life of 14.3 days was in fruits that had been precooled to 12 °C, followed by those precooled to 16 °C (12.3 days) and non-precooled fruits (10.2 days). For some crops that are stored for long periods of time hydrocooling may have little or no effect. For example after 9 months storage of Gala apples at 0.5 °C and 97% r.h. with 1% O₂ and 3%

CO₂, hydrocooling at harvest had no effect on firmness, acidity, peel colour and the incidence of internal breakdown, cracked fruit, scald and rot (Brackmann and Balz 2000). In asparagus Villanueva Suarez *et al.* (1999) showed that the speed at which fibre formation occurred was proportional to temperature, and Thompson A.K. (unpublished data) found that they could be successfully hydrocooled within 2 min. Hydrocooling of capsicums took about 10 min (Figure 24) (Hughes *et al.* 1981).

A family of standard size, reusable and recyclable plastic containers was developed to handle produce better and facilitate precooling by Hui *et al.* (1999). Results indicate that in order to provide an even distribution of water during hydrocooling, the total bottom openings should account for 5% of the total bottom surface for containers having sidewall openings located at a height of 10 mm or more, measured from the bottom of the container. Furthermore, this percentage of the total bottom surface could be reduced to 3.5% for containers having sidewall openings located over 20 mm from the container bottom.

Talbot *et al.* (1991) reported the use of hydrocooling in the United States and found that bulk sweetcorn took about 60 min to cool from 30 to 5 °C in a well-managed hydrocooler, while crated sweetcorn took about 80 min. However, sweetcorn is a low acid vegetable and once wet it would be difficult to dry and might lead to bacterial growth that could cause rotting. Miller and McDonald (2000) found that cooling carambola with iced water greatly reduced fruit quality compared with ambient air, ambient water and refrigerated air treatments. In contrast, Vigneault *et al.* (2007) found that hydrocooling of perpendicular orientation of corn cobs reduced significantly the cooling time and retained TSS, moisture content and quality for up to 21 days at 1 °C and 90–95% r.h. They also commented on the importance of sanitation of water to avoid the contamination by spoilage organisms. Hydrocooling was reported to be the most effective method (Table 7) since it rapidly cooled the fruit and had no detrimental effects on their quality. Lutz and Hardenburg (1968) reported that hydrocooling was an effective method of cooling radishes and using chlorinated water reduced black spot disease. Mencarelli (2002) found that truffles could be hydrocooled but excess water should be removed in a well-ventilated room at 4–5 °C.

Table 7 Effects of precooling method on the half-cooling time of apples packed loosely in 18 kg boxes (source: adapted from Hall 1972)

Cooling method	Half cooling time
Conventional cool room	12 h
Tunnel with air velocity of 200–400 m min ⁻¹	4 h
Jet cooling with air velocity of 740 m min ⁻¹	45 min
Hydrocooling (loose fruit)	20 min

Vacuum cooling

Cooling is achieved by the latent heat of vaporization rather than conduction. At normal air pressure of 760 mm Hg water will boil at 100 °C. As air pressure is reduced so the boiling point of water is reduced, and at 4.6 mm of mercury water boils at 0 °C. For every 5 or 6 °C reduction in temperature, under these conditions, Barger (1963) found that the crop would lose some 1% in weight. The speed and effectiveness of cooling is related to the ratio between the mass of the crop and its surface area (Table 8) so it is particularly suitable for leaf crops such as lettuce. In forced-air cooling the air passes over the surface of the crop cooling the outside, while the inside is cooled by heat transfer from inside to the outside of the crop. In contrast, with vacuum cooling of leaf vegetables such as lettuce, the reduced pressure is exactly the same around the leaves in the centre as it is around the leaves on the outside. This means that the cooling is very even and quick throughout the crop. Where there is a low ratio between mass and surface area or

Table 8 Product temperature after 25–30 min vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of –1.7–0 °C. The original product temperature was 20–22.2 °C. (source: adapted from Barger 1963)

Crop	Temperature after 25–30 min (°C)	Crop	Temperature after 25–30 min (°C)
Courgettes	18	Celery	7
Potatoes	18	Artichokes	6
Potatoes (peeled)	15½	Peas	6
Carrot roots	14	Broccoli	5½
Snap beans	12	Brussels sprouts	4½
Cauliflower	10½	Corn	4½
Cabbage	7	Carrot tops	2
Asparagus	7	Lettuce	1
		Green onions	1

there is an effective barrier to water loss from the crop surface, vacuum cooling can be slow. Also crops such as tomatoes, which have a relatively thick wax cuticle, are not suitable for vacuum cooling.

Vacuum coolers have to be strongly constructed to withstand the vacuum (Figure 25) and therefore tend to be expensive to construct. They are made from heavy-duty steel and are usually cylindrical in shape, to withstand the low pressure. The vacuum is usually achieved by a vacuum pump attached to the cylinder, and the moisture from the crop is condensed on cooling coils situated on the outlet from the cylinder to the pump. In spite of this high cost they are probably used for most lettuce marketed in Europe and the United States because the method is so quick.

Loss of water during marketing of crops not only affects their value where they are sold by weight but can also affect their value because of loss of quality. In order to reduce this problem with vacuum cooling, the crop may be sprayed with water before loading it into the vacuum cooler. Special vacuum coolers have been developed called Hydrovac coolers which

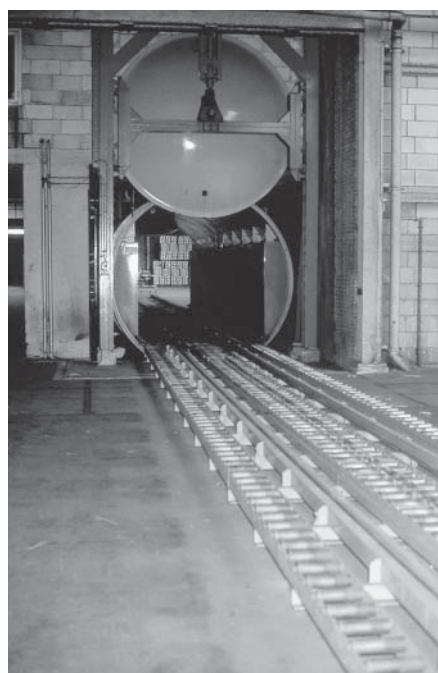


Figure 25 A vacuum cooler in operation at a fruit and vegetables storage and packaging company in Holland. Note that one end of the cooler opens to the packhouse and the other end to a cold room.

have a built-in water spray inside the cooler, which is activated towards the end of the cooling operation. Martinez and Artes (1999) found that the levels of both pink rib and heart leaf injury of winter harvested Coolguard iceberg lettuce were reduced by vacuum cooling after storage for 2 weeks at 2 °C and then held for 2½ days at 12 °C for shelf life compared with non-precooled lettuce.

Vacuum precooling was recommended by Aharoni *et al.* (1989) for French sorrel leaves. Crated sweet-corn could be vacuum cooled from about 30 to 5 °C

in 30 min (Brecht 2002). Results of trials with vacuum cooling of lettuce by Rennie *et al.* (2001) showed that changing the pressure reduction rate had no effect on the mass loss, temperature reduction per percentage mass loss or the temperature difference between various locations. The significance of these findings is that vacuum coolers with smaller vacuum pumps (slower pressure reduction rate) could be designed without any changes to the cooling characteristics of lettuce within the pressure reduction rates used in the study.

5

Packaging

The function of a package is primarily to contain and protect the produce. With fresh fruits and vegetables there are often two levels of packaging. The first is the pack in which the produce is offered to the consumer. The second is the pack that contains the consumer pack and is used to transport the product to the retail market. The size of the package is therefore important; the consumer pack should be designed in terms of the amount the market or customer requires in a single unit. In some circumstances the overall package size may be dictated by what a person can reasonably lift or carry. At least one British supermarket has a maximum weight for the overall package in order to protect their staff from having to handle heavy weights.

The length of journey, the environmental conditions, the type of handling and any hazard influence packaging in relation to protection of the produce. The cost and cost-effectiveness of the package and whether it is easy to assemble, fill and close are primary considerations. The use of standard pallets is increasing and the package may have to be designed to fit these or to fit a standard refrigerated container. Fresh fruit and vegetables being living organisms give out heat and gases that can be detrimental if allowed to accumulate in the package so they may need to be ventilated. Certain types of packaging can be used to

extend the storage life of crops, such as using plastic films to modify the atmosphere around the crop, or to protect it from infection or infestation. Root crops can be packed into material such as coir dust, peat (Figure 26) or even sawdust to protect them and provide a humid environment to preserve the crop (Thompson *et al.* 1973). The package may also help in presentation of the crop to enhance its value or help its sale. There are often legal requirements for consumer or wholesale packs where information on the origin, type, and grade of the product need to be displayed on the outside of the pack.

Most fruit and vegetables are harvested and placed in a container for transport to a packhouse or directly into a store. In many cases the crop is packed into a container in the field, and it stays in the same container right through to the wholesale market or even the retail market. The advantages of this are that the crop is only handled once so the potential for causing mechanical injury to it is reduced. Also handling takes time and labour, both of which can be expensive. The construction, operation and maintenance of a packhouse can likewise be expensive, and direct field packing can eliminate the necessity of having a packhouse. In Europe fruit and vegetable packhouses must comply with the provisions of European Council directive 93/43/EEC.



Figure 26 Sweet potatoes packed in coir dust.

Types of packaging

No packaging

This is unusual because it is normally time consuming to handle each fruit or vegetable individually and it leaves them unprotected from handling damage. In many developing countries fruit such as melons, plantains and pumpkins and root crops such as yams and cassava are just stacked into the backs of lorries for transport to the market. A certain level of damage is inflicted on the crop, but this is tolerated because it is perceived that it would be less cost effective to use packaging to reduce the damage.

In many cases banana bunches are carried from the field balanced on people's heads or shoulders, but bruising and neck damage to the banana fingers are normally a consequence. Wooden trays padded with plastic foam (Figure 27) on which the bunch is placed will reduce this damage (Stamford *et al.* 1971). Mechanical means are also used to transport banana bunches from the field, which consist of overhead cableways running throughout the banana plantation (Figure 28). These cableways have miniature trolleys, which run on the cables from which the banana bunches are suspended. The trolleys are connected together in groups to form train that is then towed together to a packhouse where the cables converge. A labourer, an animal or a small tractor may pull the trains.

Second-hand containers

Harvesting produce into cartons, wooded boxes or metal cans, which have been used for other



Figure 27 Banana clusters packed on trays for transport from the field to the packhouse.



Figure 28 Experimental cableway in St Lucia compared with the traditional 'heading' of bunches on the hillside plantations. (Source: Kemp and Matthews 1977.)

commodities, is common practice for small-scale farmers in many developing countries. The Sudan imports tomato paste in 10 kg cans. After the pulp has been used the cans are reused by local farmers for harvesting fresh tomatoes, and they became the standard measure on local markets. Second-hand

containers must be clean especially where they are used for products that are to be consumed unwashed or uncooked because of the contamination risk (John Love 1994, personal communication).

Bags and sacks

Many crops are harvested into bags that may be made from a variety of materials such as paper, polyethylene film, sisal, hessian (Figure 29) or woven polypropylene. This provides a relatively cheap method but gives only little protection to the crop from handling and transport damage. They are commonly used for crops such as potatoes, onions, cassava and pumpkins, where some damage occurs to the fruit, but the extra cost of packing them in such a way that there was no damage would be uneconomical. For high risk products woven baskets and sacks are not acceptable in many countries because of the risk of contamination (John Love 1994, personal communication). Crops such as sugar peas, mange tout or fine beans destined for export from East Africa should not be harvested into woven natural fibre bags because of contamination (Chris Anstey 1994, personal communication). The amount packed in each bag is important. If a bag is too heavy the contents are more likely to be damaged. An example of this is cassava in Colombia that is packed into sacks containing about 75 kg. These are carried on a man's back to a lorry or from a lorry to a wholesale outlet. Because the sacks are so heavy the carrier almost invariably drops the bag that damages the contents.



Figure 29 Hessian sacks used for transporting pumpkins from Jamaica to Britain.

Sacks are traditionally made from fibres that are extracted from plants, cleaned, dried, spun and woven into sheets. Commonly used fibres are jute (*Corchorus capsularia* gives the best quality, but *C. olitorius* is also used) and sisal (*Agave sisalana*). The former is a native of India and the fibre is harvested from the inner bark. They are locally called gunny bags. The fibres are fine and shiny but are injured by exposure to water. For non-returnable transport, sacks are made from plain woven jute of 250 g m^{-2} or less. Sisal is a native of Central America and the fibre is extracted from the leaves. It is more water resistant than jute but cannot be spun as finely as jute is spun. Fibres from kenel (*Hibiscus cannabiss*), hemp (*Cannabis saliva*) and abaci (*Musa textilis*) have all been used to make sacks for handling of crops. Woven sacks provide good ventilation but give almost no protection against mechanical injury.

Paper bags are made almost exclusively from natural kraft, which is a strong brown paper, made from wood pulp. It is prepared by a sulphite process and is not bleached. Semi-bleached kraft and fully bleached kraft, which are off-white and white in colour, respectively, are not commonly used for fresh produce. To make bags more resistant to water two sheets may be stuck together with bitumen making what is called union kraft. Coating one side of the kraft with extruded low-density polyethylene film can make a more effective water-resistant bag. Many materials can be mixed with the wood pulp during the manufacture of the kraft to give specific properties. These include various woven and extruded plastics and natural fibres. In some cases a transparent panel may be set into the bag to enhance the presentation of the crop. Paper quality is specified on weight per unit areas, which is called grammage in the trade. For fresh produce, kraft of about $70\text{--}100 \text{ g m}^{-2}$ is commonly used often as multiwalled bags for crops such as potatoes. Paper bags may be closed with ties by sewing or by gluing. For potatoes the bags usually contain 5, 10 or 25 kg. Paper bags are made by cutting the sheets to the appropriate size, folding them and sewing up two sides leaving one side open in which to load the crop.

Woven baskets

Baskets are traditional containers into which crops are placed at harvest (Figure 30). They have been used in most countries and are of a variety of designs. They



Figure 30 Woven basket used for field packing of a variety of crops. Here they are being used for cauliflowers in the Cameron Highlands in Malaysia.

are usually made from split bamboo, rattan or palm leaves that are woven to form traditional-shaped containers and are usually conical in shape, or if they are squarish or rectangular they tend to have sloping sides and rounded corners because of the way they are made. Construction is normally by hand and often provides an important craft industry at the village level in many less developed countries. Baskets provide very good ventilation for crops, but because the materials from which they are made are rough, they can often damage the crop by abrasion when the baskets of produce are being handled and transported. Cushioning material such as paper or leaves is often used to line baskets to reduce abrasion, but this also reduces ventilation. Baskets may be made from cheap materials, but these have poor stacking strength and when placed on top of each other the weight of the baskets is taken by the produce and not by the basket. This may lead to damage to the crop because of compression. Baskets are also difficult to stack because of their rounded, often irregular shape. This may also result in poor space utilization compared with the squared corners in boxes. Baskets that are reused for crop transport are difficult to keep clean, and may be a source of insect or microbial infection.

Wooden field boxes

Bruce boxes were made from thin pieces of wood bound together with wire and were of two sizes, the bushel with a volume of 2200 cubic inches and the

half-bushel box. They were developed in the United States where fruit were put into them at harvest for transport to wholesale and retail markets. They had the advantage that they could be packed flat when empty and were inexpensive so they could be non-returnable. However, they provided limited protection from mechanical damage during transport. The use of wires, staples or other obstacles to recycling is discouraged and the Bruce box has almost been phased out.

Rigid wooden boxes of various capacities are commonly used to transport produce from the field to the packhouse. These should be of a size that can be easily lifted, when full, by one person. They are commonly made from timber that has been sawn to the appropriate size and shape, but hardboard and plywood are also used. The boxes are then assembled usually by nailing them together, but staples or glue are also used. The amount of ventilation can be arranged easily during the construction of the box. Wooden boxes can be expensive and heavy, which affects their use in crop handling. To make their use economic it is often important to use the same box over many journeys. Being relatively heavy they are not suitable for packing crops that are to be transported by airfreight. Most boxes are rigid and have good stacking properties. However, they are often made from cheap unplanned wood whose rough surface can cause damage to the crop during transport (Figure 31). Also the way they are constructed, especially when nailed, can damage the crop. Many



Figure 31 Wooden boxes used for transporting fruit and vegetables in Eritrea. See colour plate section.

wooded boxes are made by hand, which can result in slight variations in size and shape that in turn can make them difficult to stack on lorries or in store rooms. Wood can take up moisture and if not properly cured it can lose moisture and become distorted. Non-standard sizes can make them difficult to stack on lorries or in stores, and unplanned inner surfaces or protruding nails can damage produce. Field boxes are made from thin pieces of wood, which are widely spaced, so that they are light in weight and cheap to make. These may be used for crops such as cabbages for transport from the field to the market. Wooden boxes are not acceptable to many UK supermarkets (John Love 1994, personal communication) because they may harbour microorganisms.

Plastic field boxes

These are recyclable and are used many times because they are strong and durable. Many are designed in such a way that they can nest inside each other when empty, to facilitate transport, and stack one on top of another when full (Figure 32). Others have metal bars that facilitate the nest stack design (Figure 33). Plastic boxes are strong, have good stacking strength and, if correctly made, a smooth surface. This means that they give good protection to the produce during handling and transport. They are completely water resistant and therefore easy to keep clean. They tend to be expensive and therefore each box has to be used many times to make them economic. If a suitable system can be devised for returning the boxes to the

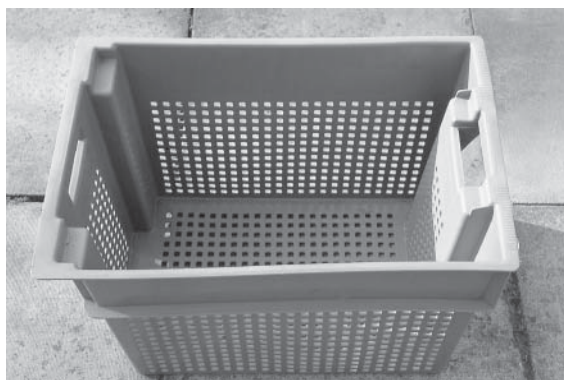


Figure 32 Plastic box of the nest stack type, where they nest if stacked all facing the same way and stack if each alternate one is 180° orientated from the one below.



Figure 33 Plastic box, containing mangosteens, where they nest when the metal bar is flipped outwards and stack when they are in place as in the picture.

field from the market, plastic boxes can provide a very economical system for crop handling.

For supermarkets they must be washed with potable water before they are reused, and lining boxes with old newspaper, grass, straw etc. is not acceptable for high risk produce (John Love 1994, personal communication). Some plastic boxes produced in large quantities can be used for single journeys for high value crops. In Thailand fresh litchis and longans are packed in such boxes for export to Singapore (Figure 34). Expanded polystyrene boxes have been used for many years for non-returnable transport of crops such as watercress.

Most plastic boxes used for crops are made by injection moulding. This involves subjecting the molten



Figure 34 Longans packed in non-returnable plastic boxes in the field in Thailand awaiting export.

plastic to very high pressures to force it into the appropriate mould. This means that the equipment for making the boxes is very expensive since it has to be sufficiently robust to withstand conditions of high temperature and pressure. The cost of the plastic from which the boxes are made is relatively cheap, so this type of box can be produced much cheaper where very large quantities of the same design and dimensions are required. The materials used are high-density polyethylene, polypropylene or polyvinylchloride. Polyethylene has higher impact strength, a lower rate of degradation when exposed to ultraviolet radiation and a slightly higher density than polypropylene. Both plastics will deteriorate under field conditions, and ultraviolet protection chemicals should be added to the plastic during manufacture to reduce the rate at which they become brittle.

Biodegradable plastic material was developed as a response to environmental concerns. One such material is polyhydroxybutyrate, which is a thermoplastic polymer marketed as 'Biopol', which can easily be broken down by soil bacteria. It is made by fermentation of sugars by a naturally occurring soil bacterium that produces it and stores it as an energy source. It can be used for injection moulding, can withstand temperatures of up to 100 °C and most closely resembles polypropylene (R.P. Pearson 1991, unpublished report). Another biodegradable material was marketed as 'CornPak'. It was developed in 1990 at the University of Illinois, the United States and was marketed by Arcola Grain Products Incorporated. It was made from ground puffed corn with soya bean lecithin and trace amounts of newspaper that was formed into 19 mm diameter spheres. The marketing company claimed that in the United States over 35,000 tonnes of Styrofoam pellets were used each year by the packaging industry that is equivalent to 20 million bushels of corn if it were replaced by CornPak.

Collapsible plastic boxes are available, which have the advantage of being packed flat when empty and thus taking up little space when being returned to the field. They have a shorter life than other types of plastic boxes, and it takes a little time to assemble them. A system based on collapsible plastic boxes was developed by IFCO (Figure 35) and had been used in the fruit and vegetable packing industry.

Expanded polystyrene is used for fresh produce. They are light and have good stacking strength but are

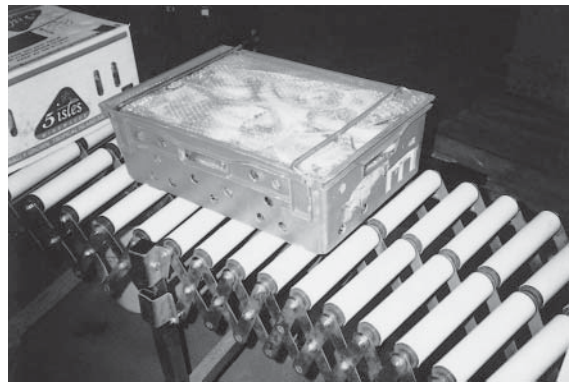


Figure 35 Reusable collapsible plastic box from the IFCO design used in banana transport trials from the Windward Islands to Britain.

brittle and easily damaged. They have good insulation properties, which means that they can protect cooled crops from rapid rises in temperature when they are removed from a cold room to an environment where the temperature is high. However, they will retain respiratory heat of the crop and fruit must be adequately precooled before the boxes are lidded, and they are also not ideal for the United Kingdom because they are not recyclable and tend to blow away when empty (John Love 1994, personal communication).

Pallet boxes

The size of pallet boxes can vary but they are most commonly based on the standard size for a European pallet of 1 × 1.2 m and they are usually about 0.5 m high. These have a capacity of about 500 kg depending on the crop they contain. They are made from wood or plastic and are used for a whole range of crops. The produce is commonly loaded into them in the field and then transported directly to the store or packhouse.

Fibreboard boxes

These are made from either laminated fibreboard or, more commonly corrugated fibreboard. They may be used for transporting produce from the field to the packhouse in which case the same carton may be used on several occasions. A study showed that in certain circumstance using corrugated cartons for transporting yams from the field to the packhouse could be economic because of reduced injury to the tubers

even when the cartons were used only once (Thompson 1972a, 1972b). However, this type of box, when used in the field is normally for produce that will go in the same pack throughout the marketing chain. A study of field packing of papaya fruit showed considerably less damage to the fruit and less postharvest disease than fruits packed in packhouses (Thompson and Lee 1971). Using cartons directly in the field is not acceptable to the supermarket sector because they may get dirty and contaminated in the fields. Boxes are also made of mixtures of fibreboard and plywood or hardboard. The reasons for these mixtures are either to reduce the cost of the box or to make it lighter and more durable.

Fibreboard boxes are made from either wood pulp or recycled paper, although other materials have been used for example popcorn (Daily Telegraph, 31 October 1990), but this increased packaging costs by 40%. The result, however, was an edible box but it had only a short shelf life. Other non-wood pulps have been made from bagasse, bamboo, straw, etc. The softwood pulp, usually from *Pinus* spp., is formed into sheets that are called kraft (from the German word for strength). The kraft can be described as virgin where the fibres are processed straight from the tree, or recycled where they have been obtained from waste paper, fibreboard boxes etc. The American Paper Institute defines virgin kraft as that which contains at least 80% new fibre, which is not more than 20% recycled fibre. The kraft is then made up into either solid fibreboard or corrugated fibreboard.

Other facing materials are:

- Jute, also called test and cylinder, which is usually made from reprocessed used fibreboard boxes. It may be made in layers of different composition or it may be homogenized.
- *Schrenz*, also called chip or bogus, which is made from recycled fibre of whatever type might be available, even used newsprint. It is naturally greyish in colour and inferior in strength characteristics.
- Laminates, which are two-ply sheets, often one layer of kraft and one layer of *schrenz*.

Solid fibreboard is not commonly used for fresh produce packing but it can provide an attractive container. It is made from layers of kraft that are glued together to produce the required thickness of board. Specifications of solid fibreboard are based on the total board thickness, which varies in the

range of about 0.8–3 mm, or weight of board per unit area, which varies from about 500 to 2000 g m⁻² for fresh produce boxes. The kraft used for the manufacture of solid fibreboard is usually between 60 and 160 g m⁻² with a white kraft outer facing which gives an attractive appearance. Water-insoluble adhesives and resin additives are used for solid fibreboard boxes that are to be used for fresh produce to increase their strength when stored in high humidity conditions. Coating with wax, nitrocellulose or polyethylene increases their resistance to water penetration.

Corrugated fibreboard boxes are more commonly used for fresh produce because they are, weight for weight, stronger than solid fibreboard boxes. The basic corrugated fibreboard boxes are made from three layers of kraft; two outer layers which are called facings or liner boards and an inner layer which is called the fluting structure or the corrugating medium. This is called single wall board. Double wall board is made from three facings and two flutings. One factor that affects the strength of the board is the fluting contour, which is defined on the height of each flute and the number of flutes (Table 9).

The characteristics of board made from the different flute structures can vary considerably. A-flute board is more susceptible to manufacturing and handling damage, but theoretically it should have good column crush strength and therefore good stacking strength. However, with commercially produced board, because of its fragility, its stacking strength is rarely better than C-flute. A-flute has the greatest cushioning effect of all the types of corrugated board. B-flute has the highest flat crush and is the most resistant to damage during manufacture and handling. It has the narrowest width and therefore poor compression strength and poor stacking characteristics. C-flute has properties between those of A-flute and B-flute but historically it was developed after A-flute and B-flute, hence its alphabetical place. It was developed in the hope of combining the top

Table 9 Number and height of flutes used in the construction of fibreboard used for fresh fruit and vegetables

Flute contour	Flutes per linear metre	Flute height (mm)
A	108–128	4.76
B	154–174	2.38
C	128–148	3.57

to bottom compression strength of A-flute and the high flat crush and greater control over fabrication of B-flute. All three flutes are still in use, particularly B-flute and C-flute. For double wall board, combinations of AB, BA, AC, CA, BC and CB are all used. Combinations of two identical flutes such as AA, BB or CC are uncommon. There is another flute, called either D or E flute, which has some 305 corrugations per metre and a flute height of about 1.19 mm, but it is not normally used for fresh produce.

The material used for the manufacture of the fluting needs to have good stiffness and formability. The highest quality fluting material is made from 'semi-chemical', which consists of hardwood fibres made by a neutral sulphite or comparable process that is partly chemical and partly mechanical because of the difficulty in defibring hardwoods. The appearance and other characteristics may vary depending on the species of hardwood used. Other fluting media include bogas, kraft and straw. Bogus is based on recycled kraft waste and if properly made can be of good quality. Kraft can be used where high tear and puncture resistance is required, but it does not corrugate well. Straw is little used since it produces an inferior fibre. Unbleached virgin coniferous kraft is most appropriate for liner materials for boxes to be used for fresh produce. It has a low rate of moisture uptake, compared with liners made from recycled material, high tearing resistance and good stiffness. Where recycled materials have to be used, a substance increase of 50% or more may be necessary to achieve a similar strength to virgin kraft.

The characteristics of the fibreboard boxes are also greatly affected by the weight of the board used. For kraft liner board these normally vary between 125 and 450 g m⁻², for jute 210–490 g m⁻² and for semi-chemical fluting 112–180 g m⁻², 112–127 g m⁻² for normal use and 150–180 g m⁻² for heavy-duty applications. Single wall board is usually made from liners of similar weight. Specifications for fibreboard are governed by specific standards, e.g. Rule 41 of the Uniform Freight Classification of the USA. Other countries also have their own specification, e.g. Fibreboard Case Specifications BS 1133(7) in the United Kingdom and AFNOR NF Q 12-008 in France. There are a whole series of standard tests for fibreboard and fibreboard boxes, such as vertical impact test, horizontal impact test, transit vibration test and bursting strength.

Fibreboard boxes easily take up moisture from the atmosphere. This affects the strength of the boxes and therefore their ability to protect and contain the crop. To make the boxes more resistant to water penetration waxes can be applied to them. These are commonly blends of microcrystalline paraffin wax with additives such as polyvinyl acetate and latexes. Paraffins by themselves are unsuitable because their melting points are too low and they fracture easily. Coatings may be applied during fabrication of the fibreboard. Sufficient coating must be applied to ensure that the board is sufficiently water resistant but not too much as this may inhibit the effect of the adhesive used in the assembly of the board. Coatings may also be applied to the board or the box.

The design of boxes made from fibreboard takes into account the need to protect the crop, display it to its best advantage and supply it in units that are required or preferred by the market. These designs have evolved over several decades and can be described by code numbers in accordance with the International Fibreboard Case Code (Export Packaging Note Number 19, International Trade Centre, United Nations Centre for Trade and Development and the General Agreement on Tariffs and Trade) (ITC 1992). The system was devised by Johan Selin in 1958 and allocates a series of letters to a box or case design. The first two letters in the code describe the basic type of box as follows:

- 02 – slotted type boxes
- 03 – telescopic type boxes
- 04 – folder type boxes and trays
- 05 – slide type boxes
- 06 – rigid type boxes
- 07 – ready glued cases
- 09 – interior fitments such as liners, pads and partitions.

Package recycling

Packaging is very expensive and its disposal after use can be a major source of pollution. Packaging creates a waste problem. New laws are being enacted in many countries on disposal of packaging. In Germany a company was set up as long ago as 1990, called Duales System Deutschland GmbH, to establish a household-orientated system for collecting used

packaging for recycling in a way that is easy for people to use and is environmentally friendly. Over 400 companies have joined the scheme, which permits them to put the Duales System Deutschland GmbH logo on their package. The logo is called *der grüne punkt* (green dot). Only packaging that can be recycled after collection is allowed to carry the *der grüne punkt* symbol. Companies are licensed to use the symbol, for which they must pay a fee. Since then many recycling schemes have been developed throughout the world. In Britain most local authorities run a voluntary recycling scheme for household waste.

Modified atmosphere packaging

Modified atmosphere packaging can be defined as an alteration in the composition of gases in and around fresh produce by respiration and transpiration when such commodities are sealed in plastic films (G. E. Hobson, 1997, personal communication). For fresh fruits and vegetables this is commonly achieved by packing them in plastic films. Plastic film bags are made from the by-products of the mineral oil refining industry. Different researchers and commercial packers use different units to describe film thickness.

Church and Parsons (1995) reviewed developments in modified atmosphere packaging. These included:

- low permeability films
- high permeability films
- O₂ scavenging technology
- CO₂ scavengers and emitters
- ethylene absorbers
- ethanol vapour generators
- tray-ready and bulk modified atmosphere packaging systems
- easy opening and resealing systems
- leak detection
- time-temperature indicators
- gas indicators
- combination treatments
- predictive/mathematical modelling.

The surface of the bag is slippery, which can make them very difficult to stack, especially large bags. Low-density polyethylene is commonly produced in this manner for the ubiquitous 'polythene' bag so frequently used in fresh produce packaging. The

permeability of plastic films to gases and water vapour will vary with the type and thickness of the plastic that is used. Generally, the acceptable time that fruit can remain in a modified atmosphere varies with cultivars and storage conditions, but it is usually 2–4 weeks, which meets the requirement of export shipment and marketable life.

Packing crops into plastic film bags can lead to a build-up of water vapour and the respiration gases ethylene and CO₂ and a reduction in O₂. The effects of these gas changes may have beneficial or detrimental effects on the crop. The beneficial effects, which can result in packing crops in plastic films, have led to this method being referred to as *modified atmosphere packaging* (Kader *et al.* 1989). *Modified atmosphere storage* can also refer to sealing fruit and vegetables in a gas-impermeable container where respiratory gases change the atmosphere over time.

If a crop is in equilibrium with its environment the rate of gas exchange will be the same in both directions. So if the concentration of the respiration gases around the outside of the crop is changed by surrounding it with plastic film, this will change the concentrations of the gases in the cells of the crop. The concentration of these gases will then vary with characteristics such as the type and thickness of the film used and innate crop characteristics such as mass of produce inside the bag, type of crop, temperature, maturity and activity of microorganisms.

Given an appropriate gaseous atmosphere, modified atmosphere packaging can be used to extend the postharvest life of crops in the same way as controlled atmosphere storage for example with mushrooms (Lopez-Briones *et al.* 1993). Another example was given by Pala *et al.* (1994). They studied storage in sealed low-density polyethylene film of various thicknesses at 8 °C and 88–92% r.h. on green peppers and found that non-wrapped peppers had a shelf life of 10 days compared with 29 days for those sealed in 70 µm low-density polyethylene film (Table 10). This method of packaging also gave good retention of sensory characteristics.

Batu and Thompson (1994) stored tomatoes at both the mature green and the pink stages of maturity either not wrapped or sealed in polyethylene films of 20, 30 or 50 µm thickness at either 13 or 20 °C for 60 days. All pink tomatoes that were not wrapped were overripe and soft after 30 days at 13 °C and after 10–13 days at 20 °C. Pink tomatoes in polymeric

Table 10 Number of days during which green pepper fruit retained either good or acceptable quality during storage at 8 °C and 88–92% r.h. (source: adapted from Pala *et al.* 1994)

	Days in storage	Sensory score ^a				Storage time (days)	
		A ^b	C ^c	T ^d	F ^e	Good quality	Acceptable quality
Before storage	0	9	9	9	9	—	—
Non-wrapped control	15	4.3	4.6	2.7	4.2	7	10
20 µm LDPE	22	5.7	5.5	5.7	5.3	10	22
30 µm LDPE	20	5.8	6.0	6.0	4.5	10	20
50 µm LDPE	20	6.0	5.0	6.0	5.0	15	20
70 µm LDPE	29	7.8	7.8	7.6	7.8	27	29
100 µm LDPE	27	5.5	5.6	5.7	5.5	10	27

^a1–9, where 1–3.9 = non-acceptable, 4–6.9 = acceptable and 7–9 = good.

^bAppearance.

^cColour.

^dTexture.

^eTaste and flavour.

films were still firm after 60 days stored at either 13 °C or 20 °C although those in 20 µm were slightly softer than those in the other two films. Green tomatoes sealed in 20 and 30 µm films reached their reddest colour after 40 days at 20 °C and 30 days at 13 °C. Fruit in 50 µm film still had not reached their maximum red colour even after 60 days at both temperatures. All green tomatoes sealed in polymeric film were very firm even after 60 days of storage at and 20 °C. Unwrapped tomatoes remained acceptably firm for about 50 days at 13 °C and 20 days at 20 °C.

The effects of polyethylene film wraps on the postharvest life of fruits may also be related to moisture conservation around the fruit and the change in the CO₂ and O₂ contents. This was shown by Thompson *et al.* (1972) for plantains where fruit stored in moist coir or perforated polyethylene film bags had a longer storage life than fruits that had been stored unwrapped. But there was an added effect when fruits were stored in non-perforated bags, which was presumably due to the effects of the changes in the CO₂ and O₂ levels (Table 11). So the positive effects of storage of fresh preclimacteric fruits in sealed plastic films may be, in certain cases, a combination of its effects on the CO₂ and O₂ contents within the fruit and the maintenance of high moisture content. The effect of moisture content is more likely to be a reduction in stress of the fruit that may be caused by a rapid rate of water loss in non-wrapped fruit. This in turn may

Table 11 Effects of wrapping and packing materials on ripening and weight loss of plantains stored at tropical ambient conditions of 26–34 °C and 52–87% r.h. (source: adapted from Thompson 1972b)

Packing material	Days to ripeness	Weight loss at ripeness (%)
Not wrapped	15.8	17.0
Paper	18.9	17.9
Moist coir fibre	27.2	3.5 ^a
Perforated polyethylene	26.5	7.2
Polyethylene	36.1	2.6
LSD ($p=0.05$)	7.28	2.81

^aThe fruit actually gained 3.5% in weight.

result in increased ethylene production to internal threshold levels that can initiate ripening.

Hansen (1975) showed that Jonagold apples kept in cold stores at 0.5, 2.5 or 3.5 °C retained satisfactory organoleptic quality only until the end of January even at the lowest temperature. However, the apples could be stored at 3.5 °C in polyethylene bags (with a CO₂ content of 7%) until April. In controlled atmosphere stores (6% CO₂ with 3% O₂ at 2.5 °C) fruit quality was satisfactory to the end of May. Under all conditions apples of this cultivar showed no rotting, CO₂ damage or physiological disorders.

Modified atmosphere packaging does not always have a beneficial effect on the postharvest life of fresh fruits and vegetables. Storing yam in polyethylene bags was shown to reduce weight loss, but have little effect on surface fungal infections and internal browning of tissue (Table 12). Geeson (1989) also showed that film packages with lower water vapour transmission properties could encourage rotting of the tomatoes.

Modified atmosphere packaging is used to slow the deterioration of prepared fruit and vegetables, and this technique is often referred to as *minimal processing*. An example of this technique is described by Lee and Lee (1996) who used LDPE film of 27 µm thickness for the preservation of a mixture of carrot, cucumber, garlic and green peppers, where the steady-state atmosphere at 10 °C inside the bags was 5.5–5.7% CO₂ and 2.0–2.1% O₂.

Film types

Different films have differences in relation to O₂ and CO₂ permeability, which is a function of

Table 12 Effects of packaging material on the quality of yam (*Dioscorea trifida*) after 64 days at 20–29 °C and 46–62% r.h.

Package type	Weight loss (%)	Fungal score	Necrotic tissue (%)
Paper bags	26.3	0.2	5
Sealed 0.03-mm-thick polyethylene bags with 0.15% of the area as holes	15.7	0.2	7
Sealed 0.03-mm-thick polyethylene bags	5.4	0.4	4

Fungal score was 0 = no surface fungal growth, 5 = tuber surface entirely covered with fungi. Necrotic tissue was estimated by cutting the tuber into two length ways and measuring the area of necrosis and expressing it as a percentage of the total cut surface (Thompson *et al.* 1972b).

thickness, density, presence of additives and gradient concentration modification (Steffens *et al.* 2007a). The manufacturing process for films has improved over the years, and although the actual thickness of the film quoted may vary slightly, the films are currently much more even and reliable. Biodegradable transparent films have been developed, including zein films. These are made from a hydrophobic protein produced from maize (Tomoyuki *et al.* 2002), but zein films may swell and deform in prolonged contact with water, which seems to restrict their use in MA packaging of fruit and vegetables. However, Rakotonirainy *et al.* (2008) reported that broccoli florets packaged in zein films (laminated or coated with tung oil) maintained their original firmness and colour during 6 days of storage. Films have been prepared by extrusion using acetylated and oxidized banana starches with LDPE. These might be feasible for making films with a high rate of degradation (Torres *et al.* 2008)

The actual concentration of gases in the fruit will also be affected to a limited degree by the amount of space between the fruit and the plastic film, but mainly by the permeability of the film. Several different plastics are used for this purpose (Table 13). A range of high shrink multilayer high-speed machineable shrink films made from polyolefin is available. Polyethylene is also used for shrink film packaging. The different types of polyethylene film were described by Schlimme and Rooney (1994):

- Low density polyethylene is produced by polymerization of the ethylene monomer, which produces a branched chain polymer with a

Table 13 A selection of plastic films which have been used for fruit and vegetable packaging

Film	Abbreviation
Cellulose acetate	CA
Ethylene vinyl acetate copolymers	EVAL
Ethylene vinyl alcohol copolymers	EVOH
High density polyethylene	HDPE
Ionomer	–
Linear low density polyethylene	LLDPE
Low density polyethylene	LDPE
Medium density polyethylene	MDPE
Oriented polypropylene	OPP
Polybutylene	PB
Polyethylene terephthalate	PET
Polyolefin	–
Polypropylene	PP
Polystyrene	PS
Polyvinyl butyral	PVB
Polyvinyl chloride	PVC
Polyvinylidene chloride	PVDC

molecular weight of 14,000–1,400,000 and a density ranging from 0.910 to 0.935 g cm⁻³. Low density polyethylene film has the following specifications: 3900–13,000 O₂ cm³ m⁻² day⁻¹, 7700–77,000 CO₂ cm³ m⁻² day⁻¹, at 1 atm. for 0.0254 mm thick at 22–25 °C at various or unreported relative humidity conditions and 6–23.2 water vapour g m⁻² day⁻¹ at 37.8 °C and 90% r.h.

- High-density polyethylene has 75–90% crystalline structure with an ordered linear arrangement of the molecules with little branching and a molecular weight of 90,000–175,000. It has a typical density range of 0.995–0.970 g cm⁻³ and has greater tensile strength, stiffness and hardness than low-density polyethylene. High density polyethylene film has the following specifications: 520–4000 O₂ cm³ m⁻² day⁻¹, 3900–10,000 CO₂ cm³ m⁻² day⁻¹, at 1 atm. for 0.0254 mm thick at 22–25 °C at various or unreported relative humidity conditions and 4–10 water vapour g m⁻² day⁻¹ at 37.8 °C and 90% r.h.
- Medium density polyethylene has a density in the range of 0.926 and 0.940, 2600–8293 O₂ cm³ m⁻² day⁻¹, 7700–38,750 CO₂ cm³ m⁻² day⁻¹, at 1 atm. for 0.0254 mm thick at 22–25 °C at various or unreported relative humidity conditions and 8–15 water vapour g m⁻² day⁻¹ at 37.8 °C and 90% r.h.
- Linear low density polyethylene combines the properties of low density polyethylene film and

high density polyethylene film giving a more crystalline structure than low density polyethylene film but with a controlled number of branches, which makes it tougher and suitable for heat sealing. It is made from ethylene with butene, hexene or octene; with the latter two co-monomers giving enhanced impact resistance and tear strength. Permeability was given as $7000\text{--}9300 \text{ O}_2 \text{ cm}^3 \text{ m}^{-2} \text{ day}^{-1}$, at 1 atm. for 0.0254 mm thick at $22\text{--}25^\circ\text{C}$ at various or unreported relative humidity conditions and $16\text{--}31$ water vapour $\text{g m}^{-2} \text{ day}^{-1}$ at 37.8°C and 90% r.h.

Film permeability

Respiring fresh fruits and vegetables sealed in plastic films will cause the atmosphere to change in particular O_2 levels to be depleted and CO_2 levels to be increased. The transmission of CO_2 and O_2 through plastic films will vary with film type, but generally films are 4–6 times more permeable to CO_2 than to O_2 . However, Barmore (1987) indicates that the relationship between permeability of CO_2 and O_2 and that of water vapour is not so simple. Variation in transmission of water vapour can therefore be achieved to some extent, independently of transmission of CO_2 and O_2 using such techniques as producing multilayer films by co-extrusion or applying adhesives between the layers. This permeability is invariably restricting, and often holes are punctured in the bags to improve ventilation (Table 14).

The permeability of films to gases (including water vapour) varies with the type of material from

which they are made, temperature, in some cases humidity, the accumulation and concentration of the gas and the thickness of the material. PE film, as indicated earlier, is available in several forms with different properties. Schlimme and Rooney (1994) showed that there was a range of permeabilities that could be obtained from films with basically the same specifications. A selection of these is summarized as follows.

Film permeability to gases is by active diffusion where the gas molecules dissolve in the film matrix and diffuse through in response to the concentration gradient (Kester and Fennema 1986). A formula to describe film permeability was given by Crank (1975) as follows:

$$P = \frac{Jx}{A(p_1 - p_2)}$$

where:

J = volumetric rate of gas flow through the film at steady state

x = thickness of film

A = area of permeable surface

p_1 = gas partial pressure on side 1 of the film

p_2 = gas partial pressure on side 2 of the film ($p_1 > p_2$).

Gas flushing

The levels of CO_2 and O_2 can take some time to change inside the modified atmosphere pack. In order to speed this process the pack can be flushed with nitrogen to reduce rapidly the O_2 , or the atmosphere can be flushed with an appropriate mixture of CO_2 , O_2 and nitrogen. In other cases the pack can be connected to a vacuum pump to remove the air so that the respiratory gases can change within the pack more quickly. Gas flushing is more important for non-respiring products such as meat or fish, but it can profitably be used with fresh fruits and vegetables. In work described by Aharoni *et al.* (1973), yellowing and decay of leaves were reduced when the lettuce cultivar Hazera Yellow was pre-packed in closed polyethylene bags in which the O_2 concentration was reduced by flushing with nitrogen. Similar but less effective results were obtained when the lettuce was pre-packaged in closed polyethylene bags not flushed with nitrogen, or when open bags were placed in polyethylene-lined cartons. Andre *et al.* (1980)

Table 14 Effects of number and size of perforation in 3 lb. (1.36 kg) 37.5 μm PE film bags of Yellow Globe onions on the relative humidity in the bags, rooting of the bulbs and weight loss after 14 days at 24°C (source: adapted from Hardenburg 1955)

IFCO perforations		Percentage of r.h. in bag	Onions rooted (%)	Weight loss (%)
Number	Size (mm)			
0	—	98	71	0.5
36	1.6	88	59	0.7
40	3.2	84	40	1.4
8	6.4	—	24	1.8
16	6.4	54	17	2.5
32	6.4	51	4	2.5
0 ^a	—	54	0	3.4

^aKraft paper with film window.

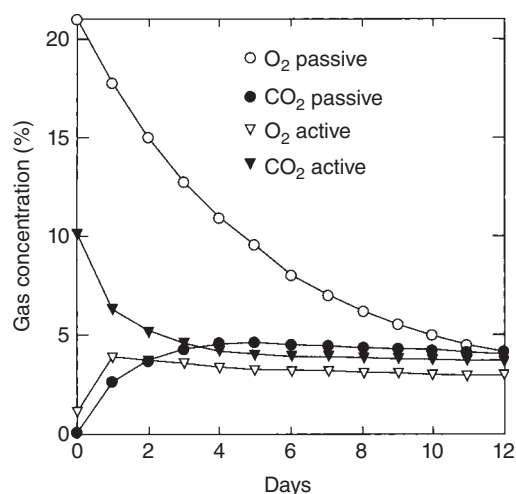


Figure 36 Simulation of a passive versus active modification of modified atmosphere packaging of chilli peppers at 10 °C in Cryovac SSD-310 film. (Source: Zagory 1990. Reproduced with permission.)

showed that fungal development during storage could be prevented in asparagus spears by packing them in polyethylene bags with silicon elastomer windows and flushing with 30% CO₂ for 24 h or by maintaining a CO₂ concentration of 5–10%.

The changes in the atmosphere inside the sealed plastic film bag depend on the characteristics of the material used to make the package, the environment inside and outside the package and the respiration of the produce it contains. This was illustrated in experiments described by Zagory (1990), which showed the effects of flushing chilli peppers stored in plastic film with a mixture containing 10% CO₂ and 1% O₂ compared with no gas flushing (Figure 36).

Modelling

Ben Yehoshua *et al.* (1995) reviewed modified atmosphere packaging under the headings: modified humidity packaging with an example of the effects on bell peppers, interactive and microporous films, effects of perforations in the film, and modelling of packaging. Day (1994) also reviewed the concept of mathematical modelling of modified atmosphere packaging for minimally processed fruit and vegetables. Evelo (1995) showed that the package volume did not affect the steady-state gas concentrations inside a modified atmosphere package but did

affect the non-steady-state conditions. A modified atmosphere packaging model was developed using a systems-oriented approach that allowed the selection of a respiration model according to the available data. Temperature dependence was explicitly incorporated into the model. The model was suitable for assessing optimal modified atmosphere packaging in realistic distribution chains. O₂ and CO₂ concentrations inside plastic film packages containing mango cultivar Nam Dok Mai fruits were modelled by Boon-Long *et al.* (1994). Parameters for polyvinyl chloride, polyethylene and polypropylene films were included. A method of determining respiration rate from the time history of the gas concentrations inside the film package instead of from direct measurements was devised. Satisfactory results were obtained in practical experiments carried out to verify the model.

Many other mathematical models have been developed and published (Cameron *et al.* 1989, Lee *et al.* 1991, Lopez-Briones *et al.* 1993), which can help to predict the atmosphere around fresh produce sealed in plastic film bags. The latter suggested the following model:

$$\frac{1}{x} = \frac{\hat{A}m}{x_0 S} \cdot \frac{1}{K} + \frac{1}{x_0}$$

where:

x = O₂ concentration in the pouches (%)

x_0 = initial O₂ concentration within the pouches (%)

$\hat{A}$ = proportionality between respiration rate and O₂ concentration including the effect of temperature (ml g⁻¹ day⁻¹ atm.⁻¹)

K = O₂ diffusion coefficient of the film (includes effects of temperature) (ml m⁻² day⁻¹ atm.⁻¹)

S = surface area for gas exchange (m²)

m = weight of plant tissue (g).

Lee *et al.* (1991) obtained a set of differential equations representing the mathematical model for the modified atmosphere system. In this case, the rate of reaction (r) is equal to:

$$r = V_m C_1 / [K_M + C_1(1 + C_2/K_1)]$$

where:

- C_1 is the substrate concentration (which is O₂ concentration in the case of respiration rate).

- V_m and K_M are parameters of the classical Michaelis–Menten kinetics.
- V_m is the maximal rate of enzymatic reaction.
- K_M is the Michaelis constant.
- C_2 is the inhibitor concentration (CO_2 concentration in the case of respiration).
- K_1 is the constant of equilibrium between the enzyme–substrate–inhibitor complex and free inhibitor.

Combining this equation with Fick's Law for O_2 and CO_2 permeation, Lee *et al.* (1991) estimated parameters of this model (V_m , K_M and K_1) from experimental data and then performed numerical calculation of the equations.

The strawberry cultivars Pajaro and Selva were used to test a model describing gas transport through micro-perforated polypropylene films and fruit respiration involved in modified atmosphere packaging by Renault *et al.* (1994). Some experiments were conducted with empty packs initially filled with either 100% nitrogen or 100% O_2 . Simulations agreed very well with experiments only if areas of approximately half the actual areas replaced the cross-sectional area of the micro-perforations in order to account for the resistance of air around the perforations. It was also possible to fit the model to gas concentration changes in packs filled with strawberries, although deviations were encountered because of contamination of strawberries by fungi. The model was used to quantify the consequences of the variability of pack properties, number of micro-perforations per pack and cross-sectional area of these perforations, on equilibrium gas concentrations and to define minimum

homogeneity requirements for modified atmosphere packaging.

Quantity of product on the gas content

The quantity of produce inside the sealed plastic film bag has been shown to affect the equilibrium gas content (Table 15), but the levels of CO_2 and O_2 do not always follow what would be predicted from permeability data and respiration load of the crop. Zagory (1990) showed that there was a negative linear relationship between weight of fresh chillies in a sealed Cryovac SSD-310 film package between CO_2 and O_2 levels, and CO_2 levels were reduced with increasing product in the bag while O_2 levels were proportionately higher. The number of fruit packed in each plastic bag can alter the effect of modified atmosphere packaging. An example of this is that plantains packed with six fruits in a bag ripened in 14.6 days compared with 18.5 days when fruits were packed individually when stored at 26–34 °C (Thompson *et al.* 1972). Zagory (1990) also demonstrated the relationship between the weight of produce in a package (20 × 30 cm) and its O_2 and CO_2 contents for one type of plastic film. The relationship between O_2 and CO_2 levels was linear (Figure 37), but varied considerably with a fourfold variation in produce weight, which illustrates the importance of varying just one factor.

Perforation

Punching holes in the plastic can maintain a high humidity around the produce, but it may be less

Table 15 Effects of the amount of asparagus spears sealed inside different film type on the equilibrium CO_2 and O_2 contents at 20 °C (source: adapted from Lill and Corrigan 1996)

Plastic film type	Permeability at 20 °C ($\text{ml m}^{-3} \text{ atm}^{-1} \text{ day}^{-1}$)	Product load (g)	CO_2 (%)	O_2 (%)
W R Grace RD 106	23,200 CO_2 , 10,200 O_2	100	2.5	9.7
W R Grace RD 106	23,200 CO_2 , 10,200 O_2	150	3.2	6.2
W R Grace RD 106	23,200 CO_2 , 10,200 O_2	200	3.5	4.1
Van Leer Packaging Ltd	33,200 CO_2 , 13,300 O_2	100	3.6	4.5
Van Leer Packaging Ltd	33,200 CO_2 , 13,300 O_2	200	4.2	3.6
Van Leer Packaging Ltd	33,200 CO_2 , 13,300 O_2	250	4.6	2.0
Chequer Systems Ltd	45,300 CO_2 , 16,400 O_2	100	3.4	15.4
Chequer Systems Ltd	45,300 CO_2 , 16,400 O_2	250	3.9	16.4
Chequer Systems Ltd	45,300 CO_2 , 16,400 O_2	3000	6.1	11.3

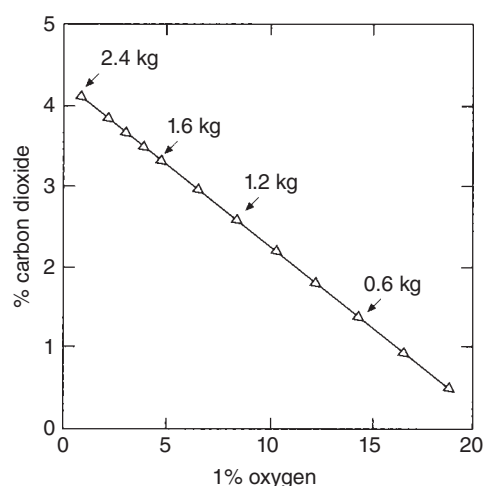


Figure 37 Equilibrium gas concentrations in modified atmosphere package as a function of product weight for chillies in Cryovac SSD-310 film. (Source: Zagory 1990. Reproduced with permission.)

effective in delaying fruit ripening because it does not have the same effect on the CO_2 and O_2 contents of the atmosphere inside the bag. The holes may be very small, and in these cases they are commonly referred to as *micro-perforations*. Various studies have been conducted on the effects of packing various produce at different temperatures on the internal gas content. Fruits of the pear cultivars Okusankichi and Imamuraaki decayed most if placed in unsealed 0.05 mm plastic bags and least in sealed bags with 5 pin holes (bags with 10 holes had more decay). Weight loss of fruit after 7 months' of storage was 8–9% and less than 1% in unsealed and sealed bags, respectively. In sealed bags, CO_2 concentration reached 1.9% after 2 months' of storage (Son *et al.* 1983). Hughes *et al.* (1981) showed that capsicums sealed in various plastic films had a higher percentage of marketable fruit than those stored in air.

Absorbents

'Active packaging' of fresh produce has been carried out for many years. This system usually involves the inclusion of a desiccant or O_2 absorber within or as part of the packaging material. These are mainly used to control insect damage, mould growth, rancidity and discoloration in a range of perishable food products such as meat, herbs, grains, beans, spices and dairy products. One such product is marketed as Ageless and uses iron reactions to absorb O_2 from the atmosphere (Abe 1990). Ascorbic acid-based sachets (which also generate CO_2) and cathecol-based sachets are also used as O_2 absorbers. The former is marketed as Ageless G[®] or Toppan C[®] or as Vitalon GMA[®] (when combined with iron), and the latter as Tamotsu[®]. Mineral powders are incorporated into some films for fresh produce, particularly in Japan (Table 16).

It was claimed that among other things these films can remove or absorb ethylene, excess CO_2 and water and be used for broccoli, cucumber, lotus root, kiwifruit, tomato, sweetcorn and cut flowers (Industrial Material Research, 1989, quoted by Abe 1990). Eun *et al.* (1997) described silver-coated ceramic coatings used on low-density polyethylene film for the storage of enoki mushrooms. Coated films extended the storage life of the mushrooms from 10 days for those stored in non-coated low-density polyethylene film to 14 days for those in silver-coated ceramic films.

Ethylene absorbents can be included inside modified atmosphere packages, and the following examples illustrate some of their uses. A major source of deterioration of limes during marketing is their rapid weight loss that can give the skins a hard texture and an unattractive appearance. Packing limes in sealed polyethylene film bags inside cartons resulted in a weight loss of only 1.3% in 5 days, but

Table 16 Commercially available films in Japan (source: adapted from Abe 1990)

Trade name	Manufacturer	Compound	Application
FH film	Thermo	Ohya stone/PE	Broccoli
BF film	BF distribution research	Coral sand/PE	Home use
Shupack V	Asahi-kasei	Synthetic-zealite	—
Uniace	Idemitsu pet chem	Silicagel mineral	Sweetcorn
Nack fresh	Nippon unicar	Cristobalite	Broccoli and sweetcorn
Zeomic	Shinanen	Ag-zeolite/PE	—

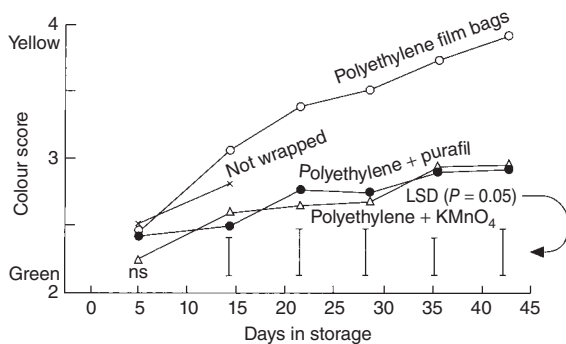


Figure 38 Effect of packaging on the colour of limes during storage in ambient conditions of 31–34 °C and 29–57% r.h. in the Sudan. (Source: Thompson *et al.* 1974.)

all the fruits degreened more rapidly than to those which were packed just in cartons where the weight loss was 13.8% (Thompson *et al.* 1974). However, this degreening effect could be countered by including an ethylene absorbent in the bags (Figure 38). Scott and Wills (1974) described experiments in which compounds that absorb ethylene, CO₂ and water were packed with cultivar William's Bon Chrétien (Bartlett) pears held in sealed polyethylene bags. After storage at –1 °C for 18 weeks in air or in bags with a CO₂ absorbent (calcium hydroxide) fruit was in poor condition externally but free of brown heart. All other fruit were stored in the presence of about 5% CO₂ and were externally in excellent condition but were affected by brown heart. The ethylene absorbent potassium permanganate reduced the mean level of ethylene from 395 to 1.5 µl s⁻¹ and reduced brown heart from 68 to 36%. The presence of calcium chloride tended to increase brown heart. The storage treatments also affected the level of six other organic volatiles in the fruit.

Proprietary products such as Always Fresh®, Ethysorb®, Purafil®, Retarder® and Sorbilen® are available, which can be placed inside the crop store or even inside the actual package containing the crop. They are made by impregnating an active alumina carrier (Al₂O₃) with a saturated solution of potassium permanganate and then drying it. The carrier is usually formed into small granules; the smaller the granules are, the larger will be the surface area and therefore the quicker their absorbing characteristics. Any molecule of ethylene in the

package atmosphere, which comes into contact with the granule, will be oxidized so the larger surface area is an advantage. The oxidizing reaction is not reversible and the granules change colour from purple to brown that indicates that they need replacing. Strop (1992) studied the effects of Ethysorb sachets in polyethylene film bags containing broccoli. She found that the ethylene content in the bags after 10 days at 0 °C was 0.423 µl L⁻¹ for those without Ethysorb and 0.198 µl L⁻¹ for those with. The rate of ethylene removal from packages using this material is affected by humidity (Lidster *et al.* 1985). At the high humidities found in modified atmosphere packages the rate of ethylene removal of potassium permanganate was shown to be reduced. Investigations were conducted to study the effect of the ethylene absorbent Sorbilen on storage quality of cabbages, carrots, cucumbers, tomatoes, grapes, cut roses and carnations. The inclusion of Sorbilen decreased storage decay of cabbages, carrots, cucumbers, tomatoes and grapes and the accumulation of the mycotoxin patulin, and contributed to better preservation of ascorbic acid and sugars in all the products (Lavrik *et al.* 2000).

CO₂ absorbents or a permeable window can be used with modified atmosphere packaging to prevent atmospheres developing which could damage the crop. The concentration of the various respiratory gases, O₂, CO₂ and ethylene, within the crop is governed by various factors including the gas exchange equation that is a modification of Fick's law:

$$-ds/dt = (C_{in} - C_{out})DR$$

where:

- ds/dt = rate gas transport out of the crop
- C_{in} = the concentration of gas within the crop
- C_{out} = the concentration of gas outside the crop
- D = gaseous diffusion coefficient in air
- R = a constant specific to that particular crop.

Companies are marketing films for which they claim can greatly increase the storage life of packed fruit and vegetables. These are marketed with names such as Maxifresh®, Gelpack® and Xtend®.

Where an ethylene absorbent (potassium permanganate) was included in the tube the increase in storage life was 3–4 times compared with unwrapped

fruit. Fruits sealed in polyethylene tubes with ethylene absorbents could be stored for 6 weeks at 20 or 28 °C and 16 weeks at 13 °C (Satyan *et al.* 1992).

The investigations on the effects of modified atmosphere conditions by Ali Azizan (1988, quoted by Abdullah and Pantastico, 1990) showed that the TSS, total TA and pH in Pisang Mas bananas did not change during storage in modified atmospheres at ambient temperature. However, Wills (1990) mentioned an unsuitable selection in packaging materials can still accelerate the ripening of fruits or enhance CO₂ injury when the ethylene accumulated over a certain period.

Adjustable diffusion leaks

A simple method of controlled atmosphere storage was developed for strawberries (Anonymous 1920). The gaseous atmospheres containing reduced amounts of O₂ and moderate amounts of CO₂ were obtained by keeping the fruit in a closed vessel fitted with an adjustable diffusion leak.

Marcellin (1973) described the use of polyethylene bags with silicone rubber panels that allow a certain amount of gas exchange, which have been used for storing vegetables. Good atmosphere control within the bags was obtained for globe artichokes and asparagus at 0 °C and green peppers at 12–13 °C when the optimum size of the bag and of the silicon gas exchange panel had been determined. Gas exchange for carrots and turnips at 1–2 °C was hampered by condensation on the inner surface of the panel. The storage life of all the vegetables was extended compared with storage in air, but losses due to rotting were high for green peppers that seemed unsuitable for this type of storage. Rukavishnikov *et al.* (1984) described 'controlled atmosphere storage' under a 150–300 µ polyethylene film, with windows of membranes selective for O₂ and CO₂ permeability made of polyvinyl trimethyl silane or silicon–organic polymers. Apples and pears stored at 1–4 °C under the covers had 93 and 94% sound fruit, respectively, after 6–7 months, whereas in ordinary storage at similar temperatures over 50% losses occurred after 5 months.

Hong *et al.* (1983) described the storage behaviour of fruits of *Citrus unshiu* at 3–8 °C in plastic

films with or without a silicone window. After 110–115 days 80.8–81.9% of fruits stored with the silicone window were healthy with good coloration of the peel and excellent flavour, while those without a silicone window were 59.4–76.8% with poor coloration of the peel and poor flavour. Controls stored for 90 days had 67% healthy fruit with poor quality and shrivelling of the peel, calyx browning and a high rate of moisture loss. The size of the silicone window was 20–25 cm² kg⁻¹ fruit giving less than 3% CO₂ and less than 10% O₂.

The suitability of the silicone membrane system for controlled atmosphere storage of Winter Green cabbage was studied by Gariepy *et al.* (1984) using small experimental chambers. Three different controlled atmosphere starting techniques were then evaluated using a cabbage cultivar imported from Florida. In each case, there was a control with the product stored under regular atmosphere at the same temperature. The silicone membrane system maintained controlled atmosphere storage conditions of 3.5–5% CO₂ and 1.5–3% O₂, where 5 and 3%, respectively, were expected. After 198 days of storage, total mass loss was 14% under controlled atmosphere storage compared with 40% under regular atmosphere. The three methods used to achieve the controlled atmosphere storage conditions did not have any significant effect on the storability of cabbage, but all maintained 3–4% CO₂ and 2–3% O₂, while 5 and 3%, respectively, were expected. In both experiments, cabbage stored under controlled atmosphere storage showed better retention of colour, fresher appearance, firmer texture and lower total mass losses compared with those stored under regular atmosphere.

Raghavan *et al.* (1982) used a silicone membrane system for storing carrots, celery, rutabagas and cabbage. Carrots were stored for 52 weeks and celery, rutabagas and cabbage for 16 weeks. The required higher CO₂ levels were achieved within the membrane system compared with normal air composition in a standard cold room. Design calculations for selection of the membrane area are also presented in the chapter.

Equilibrium modified atmosphere packaging

EMAP is the term that is commonly used for the packaging technology used for minimally processed

fruit and vegetables. The internal O₂ concentration of the packages could be predicted for the different steps of the simulated distribution chain by applying an integrated mathematical model and using highly permeable packaging films. For example Del-Valle *et al.* (2009) developed a model to determine the

EMAP for mandarin segments because of their high respiration rate. The model showed the need for using micro-perforated plastic films for the MA package. The number of micropores was optimized by monitoring the accumulation of fermentation volatile compounds for 3 weeks at 3 °C.

6

Postharvest treatments

Fruit and vegetables are living organisms and continue to respire after harvest. Aerobic respiration is the oxidative breakdown of the more complex substrates normally present in the cells, such as starch, sugars and organic acids to simpler molecules (usually CO_2 and water). These reactions produce energy and the regeneration of adenosine triphosphate (ATP) from adenosine diphosphate (ADP) and inorganic phosphate. The process involves a series of reactions, each of which is catalysed by a specific enzyme and breaks down a complex molecule to a simpler one. Where O_2 in the storage environment is absent or where it is in short supply then aerobic respiration can change to anaerobic respiration or more commonly referred to as *fermentation*. This can even occur in some tissue and not in others. For example when potato tubers or apple fruit are stored in CA conditions with very low levels of O_2 , this might be sufficient to allow aerobic respiration in the outer cells but be insufficient for the inner cells where fermentation might take place.

The storage or marketable life of crops can be extended by various treatments applied to them after harvesting. The most important of these is temperature management including the cold chain where the temperature of the crop is reduced rapidly directly after harvesting to stabilize the crop, and then it is maintained under these conditions until it reaches the consumer. Exposing crops to brief periods of high or low temperature after harvest can also have beneficial

effects particularly in pest and disease control. A variety of chemicals are applied to crops after harvest to control diseases, delay or prevent sprouting or affect the crop's metabolism. Strict legislation controls their use to protect the consumer. Waxes and other coating materials are applied to crops, but again laws control their use. Crops may be exposed to certain gases such as ethylene, or in other circumstances precautions have to be taken to protect the crops from undesirable gases.

Minerals

During growth, the crop absorbs mineral nutrients from the soil. The amount taken up depends on various factors including the amount available in the soil. If a certain nutrient is available in low quantities it can lead to deficiencies in the crop, which in turn can result in a loss of storage life or quality. Nutrient imbalance can be affected by other nutrients. If there is an excess amount of one nutrient in the soil it may be taken up in preference to another causing imbalance within the crop. It is obviously better to grow the crop on the soils that are not deficient in that particular nutrient, but this is not always possible. The usual solution to this problem is to apply the nutrient to the growing crop as either a soil fertilizer or a foliar spray, but postharvest application can also be beneficial. The postharvest application of calcium can be used for

apples to reduce the development of physiological disorders occurring during storage, particularly bitter pit (Sharples *et al.* 1979). Postharvest application of calcium has also been shown to inhibit ripening of tomatoes (Wills and Tirmazi 1979), avocados (Wills and Tirmazi 1982) and mangoes (Wills and Tirmazi 1981). In these three cases the calcium was applied by vacuum infiltration (250 mm Hg) with calcium chloride at concentrations within the range 1–4%, higher concentrations could result in skin damage. These treatments were found significantly to delay ripening without affecting fruit quality. Vacuum (32 kPa) and pressure infiltration (115 kPa) of Kensington Pride mangoes with 2–8% calcium chloride solution resulted in delayed softening of fruit during storage at 20 °C of 8–12 days compared to untreated fruit (Yuen *et al.* 1993). However, peel colour remained partially green when fruits were ripe and some peel injury occurred in treated fruit. Cling film (19 µm thick), shrink film (17 µm thick) of polyethylene bags (50 µm thick) appeared to be as effective as calcium infiltration in delaying ripening without peel injury and undesirable retention of excessive green colour in the ripe fruit (Yuen *et al.* 1993). Drake and Spayd (1983) pressure infiltrated Golden Delicious apples with calcium chloride (3% at 3 pounds per square inch for 8 min) before storage for 5 months at 1 °C. These fruit were firmer and richer in acid content than untreated fruit stored for the same period. Calcium infiltration was shown to reduce chilling injury and increase disease resistance in stored fruit (Yuen 1993). The addition of lecithin (phosphatidylcholine) to the postharvest application of calcium can enhance its effect in controlling bitter pit in apples (Sharples *et al.* 1979). At 18 °C apple fruits treated with calcium (4% calcium chloride) had a slightly lower respiration rate, but this effect was greatly enhanced when lecithin (1%) was added. At 3 °C lecithin-treated apples had reduced ethylene production but no effect on carbon dioxide production (Watkins *et al.* 1982). Duque and Arrabaca (1999) found evidence that suggested that the role of postharvest calcium in fruit ripening is not related to respiration.

Astringency removal

Astringency occurs in many fruit because of the presence of tannins. They can impart an unpleasant

flavour to the fruit and are often associated with immature fruit. In bananas tannins polymerize as the fruit ripens and they lose their astringency (Von Loesecke 1950). Treatment of persimmon with high levels of carbon dioxide can be used to reduce astringency. Storage of persimmons in 4% CO₂ at –1 °C for about 2 weeks before removal from storage followed by 6–18 h in 90% CO₂ at 17 °C removed astringency from fruits (Hardenburg *et al.* 1990). Placing fruit in a PVC film tent containing 80–90% CO₂ for 24 h reduced astringency (Kitagawa and Glucina 1984). Constant temperature short duration treatment (20–25 °C and 90–95% CO₂) of the cultivar Hiratanenashi showed that astringency disappeared 3–4 days after removal (Matsuo *et al.* 1976). Treating persimmon fruits with alcohol has been known to reduce their astringency for over 100 years in Japan. Spraying fruit with 35–40% ethanol at the rate of 150–200 ml 15 kg^{–1} of fruit was shown to have removed astringency 10 days later in ambient storage. This treatment took longer to remove the astringency than the carbon dioxide treatment, but the fruit were considered of better quality (Kitagawa and Glucina 1984).

Antioxidants

Storage disorders such as scald in apples can be controlled by a pre-storage treatment with an antioxidant. Ethoxyquin (1,2-dihydro-2,2,4-trimethylquinoline-6-yl ether) marketed as ‘Stop-Scald’ or DPA (diphenylamine) marketed as ‘No Scald’ or ‘Coraza’ should be applied directly to the fruit within a week of harvesting. Sive and Resnizky (1989) described successful application of DPA and Ethoxyquin to Granny Smith, Delicious and Golden Delicious apples in cold stores, by thermal fogging and thermonebulization. Different cultivars of apples respond differently to these treatments, for example only DPA is effective in controlling scald on the Delicious cultivars. In the United States the government approved the postharvest application of these two chemicals to apples with maximum residues of 3 µl L^{–1} for ethoxyquin and 10 µl L^{–1} for DPA (Hardenburg and Anderson 1962). Residue levels of DPA in apples were found to vary depending on the application method and the position of the fruit in the pallet box (Table 17). There are restrictions

Table 17 Residues of DPA in Granny Smith apples 1–2 months after treatment (source: Chapon *et al.* 1987)

Method of application	Position of apples in the pallet box	Residue levels (ppm)
Drenching	Top	1.25
Drenching	Middle	1.30
Drenching	Bottom	2.15
Thermofogging	Top	4.25
Thermofogging	Middle	4.65
Thermofogging	Bottom	9.60

on the sale of treated fruits in several countries, and local legislation should be consulted before the antioxidants are applied.

Sprout suppressants

Many plants produce natural vegetative storage organs. These may be the edible parts of the crop that is harvested and stored or marketed. They are often natural organs of perennation that have a dormant period and then regrow. Botanically they may be root tubers, stem tubers, corms, bulbs, swollen roots or a combination of more than one structure. As natural storage organs many of them can be stored for protracted periods of time. The limiting factor in storage is usually when the dormancy period ends and the organ regrows. Even after the dormancy period has ended, the crop might not sprout if the conditions, especially temperature, are not conducive. Methods of suppressing sprouting are dealt with under individual crop including the edible aroids, onions, potatoes, sweetpotatoes and yams.

Fruit coatings

Fruit are dipped or sprayed with a range of materials postharvest to improve their appearance or delay deterioration. A US patent was taken out on a product (Ukai *et al.* 1976) that could be used to coat fruit, which upon drying left a membrane on the surface that would controllably suppress their respiration rate. The end effect was to extend the storage life of the fruit. The composition of the coating material was water-soluble high polymer such as a polysaccharide and a hydrophobic substance selected from a group

consisting of hydrophobic solids and hydrophobic and non-volatile liquids such as natural waxes. After application to fruit the dried coating consisted of fine continuous micovoids (Ukai *et al.* 1976).

Tal Prolong

Banks (1984) described a coating called Tal Prolong, which consisted of sucrose esters of fatty acids, and carboxy methylcellulose. It was claimed that it could delay the ripening of bananas. He postulated that the effect was due to the restriction in gas exchange between the fruit and its surrounding atmosphere. This caused a build-up of CO₂ and a depletion of O₂ thus causing an effect achieved in controlled atmosphere storage. Bancroft (1989) showed some reduction in levels of disease on stored apples coated with Tal Prolong.

Semperfresh

Suhaila *et al.* (1992) found that guavas coated with a similar material to Tal Prolong, called Semperfresh, and stored for 2 months at 10 °C were in better condition than untreated fruit, but coating fruit with palm oil was more effective, and cheaper, than Semperfresh. Banana crowns coated with Semperfresh also showed delayed development of crown rot caused by infection with *Colletotrichium musae*. However, when fruits were inoculated with *C. musae* after harvest, the results were inconsistent (Thompson *et al.* 1992). The control of crown rot could be enhanced by the inclusion of organic acids to the coating material (Al Zaemey *et al.* 1993). Kerbel *et al.* (1989) showed that for Granny Smith apples coated with Semperfresh (0.75 and 1.5%) and stored at 0 °C for 4 or 5 months, ripening was delayed 'somewhat' compared to fruit with no coating. The treatments did not reduce levels of bitter pit or superficial scald (Kerbel *et al.* 1989). The company who manufactured and marketed Semperfresh was called Surface Systems International. In 1992 and 1993 they brought out a range of different formulations for different purposes. Ban-seel[®] was a liquid formulation to protect and extend the storage life of bananas and plantains. Nu-coat flo[®] was for citrus fruits. Brilloshine[®] C was to protect, shine and extend the shelf life of citrus fruit. Brilloshine[®] L was to protect, shine and extend the shelf life of apples, avocados, melons and other non-citrus fruit. Surface

Systems International also developed a formulation that could be applied to potatoes to control sprouting during storage.

Chitosan

Chitosan is a natural biopolymer, N, O-carboxymethyl chitosan, which can be used to produce films for coating fruit and vegetables that are selectively permeable to gases such as CO₂, O₂ and ethylene (Hayes 1986, Davies *et al.* 1988). It must be dissolved in an acid solution to activate its antimicrobial and eliciting properties. Chitosan-based products are available commercially, e.g. Nutri-Save, which have shown the same effectiveness as the biopolymer dissolved in an acid solution. It has been shown to reduce the growth of decay-causing fungi and induce resistance responses in host tissues and produced other effects contributing to reduced decay (Romanazzi *et al.* 2012). Chitosan has been successfully used to control brown rot (caused by *Monilinia fructicola*) on peaches (Li and Yu 2001), *M. fructicola* infections on nectarines (Casals *et al.* 2012) and grey mould in inoculated grapes (Romanazzi *et al.* 2006) and reduce the decay of blueberry during storage (Jingyun Duan *et al.* 2011). It has other properties and has been shown to improve the postharvest life of apples (Davies *et al.* 1988, Kader 1988), peppers and cucumbers (El Ghaouth *et al.* 1991), longans (Jiang and Li 2001), oyster mushrooms (Cho and Ha 1998), breadfruit (Worrell *et al.* 2002) and broccoli (Ansorena *et al.* 2011). Conversely it was shown to have no positive effects on papaya (Maharaj and Sankat 1990) and strawberries (Perdones *et al.* 2012).

Vapor Gard

Another fruit coating, marketed as 'Vapor Gard', is an anti-transparent. Its effects on the postharvest life of Harumanis mangoes were studied by Lazan *et al.* (1990). The effects of coating the fruit in a 1.3% solution was to reduce water loss, retard firmness decrease, reduce the decrease in ascorbic acid content, inhibit malic enzyme activity and increase polygalacturonase activity compared to untreated fruit.

Trehalose

Trehalose is sugar that has been tested as a coating material for food preservation (Roser and Colaco

1993, A.H. Abboudi, 1993, unpublished results). Trehalose, also known as mycose or tremalose, is a natural α -linked disaccharide formed by an α, α -1,1-glucoside bond between two α -glucose units. This makes trehalose a very stable reducing sugar that is chemically quite inert and biologically non-toxic. These properties make it a useful preservative for biological molecules and food. The sugar is thought to form a gel phase as cells dehydrate. It is prevalent in some mushrooms including shiitake (*Lentinula edodes*), maitake (*Grifola fondosa*), nameko (*Pholiota nameko*) and Judas's ear (*Auricularia auricula-judae*), which can contain 1–17% of trehalose. Trehalose is also referred to as *mushroom sugar*. Li and Tian (2007) reported that treatment with trehalose and other sugars could help retain the viability of the biocontrol yeast *Cryptococcus laurentii* in controlling postharvest diseases of apples. They also found that citric acid could induce accumulation of intracellular trehalose in *C. laurentii*. The use of trehalose in preservation of dehydrated material is covered by the European patent 0 297 887 B1 22 April 1992.

1-MCP

Ethylene is synthesized in plant material especially in climacteric fruit where copious amounts may be produced. The amount of ethylene synthesized can depend on harvest maturity, handling method, storage temperature and gaseous content around the fruit or vegetables. Postharvest exposure of plant material to 1-MCP, which is 1-methylcyclopropene, has been shown to reduce ethylene production of fruits, vegetables and flowers. De Wild (2001) even suggested that short-term controlled atmosphere storage might be replaced by 1-MCP treatment. 1-MCP is available as a commercial preparation called EthylblocTM powder. Ethylene production, respiration and colour changes in Fuji apples were all inhibited following 1-MCP treatment at 0.45 mmol m⁻³ (Fan *et al.* 1999). Watkins *et al.* (2000) showed that it reduced superficial scald incidence and accumulations of α -farnesene and conjugated trienols during air storage, but its efficacy on stored apples was affected by cultivar and storage conditions. Rupasinghe *et al.* (2000) also showed that the contents of α -farnesene and its putative superficial scald causing catabolite, conjugated triene alcohol, in the skin were reduced

60–98% by 1-MCP and the incidence of superficial scald suppressed by 30% in McIntosh and 90% in Delicious. The threshold concentration of 1-MCP inhibiting *de novo* ethylene production and action was $1 \mu\text{L L}^{-1}$. 1-MCP-treated McIntosh and Delicious apples were significantly firmer than untreated apples following cold storage and post-storage exposure to 20°C for 7–14 days (Rupasinghe *et al.* 2000). De Wild (2001) made a single application of 1-MCP directly after harvesting to Jonagold and Golden Delicious apples, followed by 6 months of storage at 1°C under controlled atmospheric conditions of 1.2% O_2 and 4% CO_2 or cold storage at 1°C followed by shelf life of 7 days at 18°C . No loss of firmness was found after the use of 1-MCP, and yellow discoloration of Jonagold decreased. Cold stored apples showed greater firmness loss than controlled atmosphere stored apples, unless treated with 1-MCP. Treated apples did not show losses in firmness during shelf life at 18°C .

With Cavendish bananas harvested at the mature-green stage, treatment with 1-MCP delayed peel colour change and fruit softening, extended shelf life and reduced respiration rate and ethylene production (Jiang *et al.* 1999). Ripening was delayed when fruits were exposed to 0.01 – $1.0 \mu\text{L L}^{-1}$. 1-MCP for 24 h, and increasing concentrations of 1-MCP were generally more effective for longer periods of time. Similar results were obtained with fruits sealed in 0.03-mm-thick polyethylene bags containing 1-MCP at either 0.5 or $1.0 \mu\text{L L}^{-1}$, but delays in ripening were longer at about 58 days.

Extension of the postharvest life of various fruit and vegetables has been reported after treatment with 1-MCP. The vegetables include aubergine (Masolo *et al.* 2011, Barbagallo *et al.* 2012), avocado (Pesis *et al.* 2002, Zhang *et al.* 2012), broccoli (Ku and Wills 1999, Ma *et al.* 2009, Cefola *et al.* 2010), capsicums (Fernández-Trujillo *et al.* 2009, Cao *et al.* 2012a, 2012b), chayotes (Cadena-Iñiguez *et al.* 2006), Chinese chives (Wu *et al.* 2009) and tomatoes (Amodio *et al.* 2005, Baldwin *et al.* 2007, Su and Gubler 2012). The fruit include apples (Guo *et al.* 2007, Johnson 2008, Watkins and Nock 2012), apricots (Fan *et al.* 2000), Chinese pears (Fan *et al.* 2000, Yazdani *et al.* 2011), durian (Sudto and Uthairatanakij 2007), figs (Gözlekçi *et al.* 2008), plums (Manganaris *et al.* 2008, Khan and Singh 2007, Singh and Singh 2012a, 2012b), limes (Jomori *et al.* 2003, Win *et al.* 2006), litchi (Sivakumar and Korsten 2007, De Reuck

et al. 2009a), mangosteen (Piriavinit *et al.* 2012), apricots (Muñoz-Robredo *et al.* 2012) and strawberries (Jiang *et al.* 2001). In some cases 1-MCP treatment had no effects including blueberries (DeLong *et al.* 2003) and strawberries where some positive effects were also observed (Jiang *et al.* 2001).

Salicylic acid

Salicylic acid ($\text{C}_6\text{H}_4 \text{ OH COOH}$) has been used for medical purposes for over a century. It is extracted from the willow (*Salix* spp.) and also occurs in the fruit of *Ribes*, *Fragaria* and *Rubus* (Hulme 1970). It has been investigated for its effects on plant material. For example immersing peach fruit in 0.10 g salicylic acid per litre and storage at room temperature resulted in a delay in the peak of ethylene production and reduction in electrolyte leakage and an initial reduction in polyphenoloxidase activity compared to fruits that had not been treated (Han *et al.* 2000). Luo *et al.* (2012) found that treating Japanese plum with salicylic acid suppressed chilling injury, reduced respiration rate and ethylene production and delayed the onset of the climacteric peak.

Sayyari *et al.* (2009) found that dipping fruit in salicylic acid, especially at 2 mM concentration, was highly effective in reducing chilling injury and electrolyte leakage in the peel of pomegranate, as well as ascorbic acid loss compared to that observed in control fruit during storage at 2°C for 3 months. Sayyari *et al.* (2012) subsequently reported that dipping fruit in 0.1 , 0.5 or 1.0 mM acetyl salicylic acid immediately after harvest reduced chilling injury and helped maintain their quality during storage at 2°C . Fruits that had been treated with acetyl salicylic acid had improved retention of sugars, organic acids, total phenolics and anthocyanins. Xu and Tian (2008) found that salicylic acid activated antioxidant defence responses of sweet cherry fruit, which may play a role in the resistance against *Penicillium expansum*. Since its importance in medicine it is not clear whether it would ever be approved for postharvest application to fruit and vegetables.

Curing

Many root crops have a cork layer over the surface that is called a periderm. This serves as a protection

against microbial infections and excessive water loss. This layer can be broken or damaged during harvesting and handling operations so curing is essentially a wound-healing operation to replace the damaged periderm and is achieved by exposure to an appropriate temperature at high humidity for a period of time. Curing is applied to fruits especially citrus fruits. The mechanism is different to root crops, but it effectively heals wounds and reduces disease levels. Drying is also carried out to aid preservation of bulb crops such as bulb onions and garlic. This does not involve drying the crop to even lower moisture content as in dehydration, but only drying the outer layers.

Lignification of injuries is an important component of defence against postharvest diseases. The effect of elicitor treatment on accumulation of lignin at 30 °C was evaluated using storage tissues of four plants. Root tissues of daikon (radishes), turnip and sweet potato all exhibited increased lignification in response to elicitation with pectinase, chitosan or a yeast extract. Acorn squash (*Cucurbita pepo*) tissue responded only to pectinase. Squash tissue elicited and then held at 28 °C for 18 h developed considerable resistance to infection by *Penicillium italicum*. The lignification process was complete within 24 h on all four plant tissues (Stange and McDonald 1999).

Hot water treatment

Crops may be immersed in hot water (Figure 39) or brushed with hot water before storage or marketing to control diseases. The principal of this treatment is that the disease-causing fungi are actively growing on fruit. After harvest the fruit are not growing. Cells that are actively dividing are more susceptible to damage and therefore it is possible to find a time/temperature regime that will kill the fungi and thus control the disease without damaging the fruit. It may also be necessary to include a fungicide in the water to achieve complete control. Additionally it has been used on fruit to control insect infestation. Hot water treatment has been applied to various crops including mangoes, papaya, citrus fruits, blueberries and sweet potatoes. Hot water treatment at 40 °C was



Figure 39 A batch mango hot water treatment facility erected on a farm in St James, Jamaica.

effective in increasing their storage life by slowing ripening and also reduced the rate of ethylene evolution in ber fruits *Zizyphus mauritiana* (Anuradha and Saleem 1998).

Vapour heat treatment

This treatment was developed to control infections of fruit flies in fruit. It consists of stacking the boxes of fruit in a room that is heated and humidified by the injection of steam. The exposure time is judged by placing a temperature probe in the centre of the fruit or alongside the seed. The temperature and exposure time are adjusted to kill all stages of the insects (eggs, larvae, pupa and adult) but not damage the fruit. The most difficult stage to control by both vapour heat treatment and hot water treatment is the larval stage because it tends to be further from the fruit surface and thus exposed to high temperatures for shorter periods (Jacobi *et al.* 1993). Hydrothermic quarantine treatment at 46.5 °C for 90 min for Tommy Atkins and Kent mangoes was described by Lizana and Ochagavia (1997) for fruit exported from Chile to the United States. Vapour heat treatment can cause injury to some fruits. McGuire (1991), Esquerra and Lizada (1990) and Coates *et al.* (1993a) reported that vapour heat treatment can also be used to control fungal diseases.

Degreening

The colour of many fruits is governed by the presence, in the skin, of carotenoids and xanthophylls, which give the fruit orange or yellow colours, respectively, and chlorophylls, which give them a green colour. The change from green to yellow or orange, associated with maturation and ripening of many fruit, may involve pigment synthesis, but in many cases it is

simply the breakdown of chlorophyll that has been masking the orange or yellow pigments (Seymour 1985). Oranges are often degreened after harvest by exposing them to ethylene gas under controlled temperature and humidity. Application of ethylene may be by an initial injection of the correct level or by continuously trickling it into the room. For citrus fruits there are various recommendations (Winston 1955, Eaks 1977, McCornack and Wardowski 1977).

7

Storage

Store management and organisation

Organisation of storage varies with the scale of the operation. On-farm crop storage is frequently carried out. With small farmers, the quantities stored are often very small, and therefore, sophisticated facilities may not be appropriate. In such cases, if crops need to be stored, it may be more economic for groups of farmers to form a storage cooperative, where the group combine to purchase and run central storage facilities. This is particularly important where complex systems are used such as controlled atmosphere stores. The expensive electronic equipment, which is used to sample and regulate the store atmosphere, is a relatively fixed cost for small or large stores. The facilities and organisation of such an enterprise can allow for purchasing and marketing at more favourable rates. This centralised type of organisation would require separate and specialised management.

Storage of fruits and vegetables is practised for various reasons. It is part of orderly marketing, where the storage period is usually short, to allow for accumulation of sufficient produce by a grower or group of growers to send to market. It may be stored on wholesale markets during the period it is being sold. Also it may be stored when the price at a particular time is low to await an increase in price. Certain crops are stored for long periods of time to extend the

duration of their availability. In this latter case, the crop is grown purposely for long-term storage, and even specific cultivars are grown. However, long-term storage can be expensive and require a high level of technical knowledge of the crop. The factors which need to be taken into account before embarking on crop storage are:

- knowledge of the appropriate storage conditions
- cultivar or variety of crop suitable for storage
- appropriate storage facilities available
- suitable management available.

The cost of storage can be very high and the following costs need to be taken into account:

- erection of storage structure
- maintenance of structure
- cost of loading and unloading crop
- possible cost of electricity
- possible cost of storage containers
- depreciation on capital.

Fruits and vegetables are living organisms. Their condition and marketable life are affected by such things as temperature, humidity, the composition of the atmosphere which surrounds them, the level of damage that has been inflicted on them and the type and degree of infection with microorganisms. They will deteriorate during storage through:

- loss of moisture
- loss of stored energy, e.g. carbohydrates
- loss of other foods, e.g. vitamins
- physical losses through pest and disease attack
- loss in quality from physiological disorders.

All these factors should be taken into account before a crop storage enterprise is undertaken. The alternatives to storage should also be examined. These alternatives may include:

- importing the crop from another region where it can be grown off season,
- growing a different cultivar which may produce a crop out of season,
- changing the method of cultivation to extend the production season or convincing the consumer to eat a crop that is in season.

If finally it is decided to go ahead with storage, the crop must increase in price during the storage period to offset the costs (Figure 40). In many cases, the retail price of a crop is relatively stable throughout the year. In a study in Zambia (Thompson 1971c), it was shown that the price of potatoes fluctuated by less than 3% in the Copperbelt and by about 7% in Lusaka, and onions by about 7% in both places. In a study of onions, the break-even price by month of controlled atmosphere storage decreased as the capacity level of the storage facility increased and as the rate of interest decreased (Hancock and Epperson 1990). If consumers accumulated a large inventory of onions or the demand was truly seasonal, the latent demand for onions over the technically feasible storage period may be insufficient to cover storage costs.

The situation may be complicated in many situations in less developed countries by the need to preserve foreign exchange and perhaps provide work for labour in the consuming country. Such factors may override purely economic considerations and crops may be stored which could be imported more economically. This principle must hold true in purely commercial situations whatever type of storage is contemplated. In many market situations, crops will be stored when their supply is in excess of demand. If such an enterprise is undertaken, there must be a reasonable assumption that the market price will rise to pay for storage costs, but with many crops, especially in less developed countries, the stored crop may be competing with freshly harvested crop which may enjoy a premium market price. There are cases where a certain amount of a crop will be stored to restrict the market supply, and subsequently released over a period of time. These subsequent prices may not be higher but the result may have overall economic advantages. This presupposes that the organisation carrying out storage is on a sufficient scale to influence prices as in the case of a national marketing board.

In some cases, fruit and vegetables destined to be processed are first stored to even out the supply to the factory. Often, the objective is to provide a constant supply of raw material for the factory for as long a time as possible because labour force and machinery are fixed costs. Often, this type of storage is different from storage of crops destined for the fresh market. This can be true both technically and from the point of view of the economic factors that

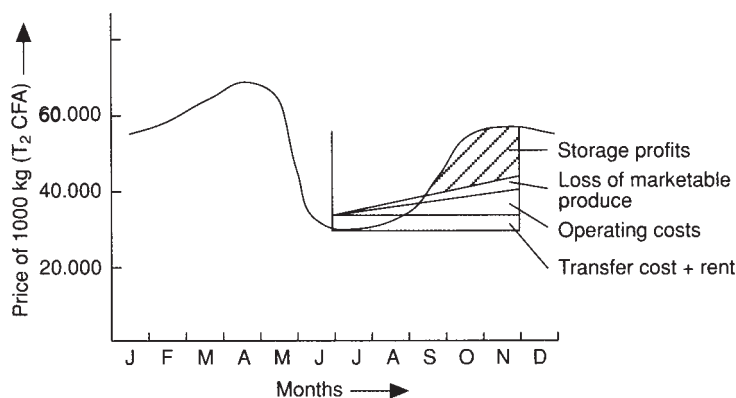


Figure 40 Prices of potatoes at Kumbo market in the Cameroon and storage costs and profits of one storage season per year. (Source: Adapted from Toet 1982.)

are used to justify storage. Technically, the crop may be stored at temperatures that would cause chilling injury when removed to higher temperatures for the fresh market. This is because crops for processing are usually processed directly from the store. If a crop is to be processed by dehydration, it may not be a disadvantage for it to lose water during storage. If this is the case, the crop for processing may be stored at low relative humidity. From the economic aspect, the processed crop may have a market all the year round but the harvest season may be only a few weeks. The crop that is processed directly after harvest may be very profitable whereas that which is processed after long periods of storage may make a loss. But on balance, the enterprise is profitable and the processor can supply the market and therefore the processor retains market share.

Store design and method

Human beings have stored crops for centuries and techniques have been developed in different societies involving varying methods and structures, some of which survive today. Stores can be grouped into those that do not require refrigeration, which are dealt with in this section. Types of simple stores are given in the following.

In situ

In situ storage effectively means delaying the harvest of the crop until it is required. It can be done in certain cases with root crops, but it does mean that the land where the crop was grown remains occupied and a new crop cannot be planted there. The crop may also be exposed to pest and disease attack. In cassava, it was shown that delayed harvest can result in reduced acceptability and starch content and the risk of preharvest losses (Rickard and Coursey 1981). In colder climates, the crop may be exposed to the detrimental effects of freezing or chilling injury.

Burying

Root crops can be packed into material such as coir dust, peat (Figure 26) or even sawdust to protect them and provide a humid environment to preserve the crop (Thompson 1972a, 1972b). CIP (1992)

Table 18 The effects of packaging material on storage losses of potatoes after 2 months in ambient conditions (source: adapted from CIP 1992)

Medium	Weight loss (%)	Rotting loss (%)
Sand	15.4b	20.0a
Brick-kiln soil	8.7c	8.6b
Dried soil	12.7b	9.8b
Wood ash	19.8a	6.2b
Rice husks	20.7a	18.0a

Figures followed by the same letter were not significantly different ($p = 0.05$).

compared storage of root crops for 2 months in tropical ambient conditions buried in various materials. It was found that brick kiln soil gave lower storage losses (Table 18). In India, potatoes are traditionally stored buried in sand. Maintaining high humidity around fruit such as plantains can help keep fruit in the preclimacteric stage so that when fruit are stored in moist coir dust, they can remain green and preclimacteric for over 20 days in Jamaican ambient conditions (Thompson *et al.* 1972a, 1972b).

Pits

Placing the crop in a pit or trench is a traditional way of storage used in many countries. The pit or trench is dug at the edges of the field where the crop has been grown. If the field slopes, it is important that the pits or trenches are placed at a high point in the field especially in regions of high rainfall. The pit or trench may be lined with straw or other organic material, filled with the crop to be stored, covered by a layer of organic material and then a layer of soil. Sometimes, wooden boards are placed on the soil surface before the soil is put on. The lack of ventilation may cause problems with rotting and ventilation trenches may be dug down to the base of the store. Ventilation holes may also be left at the top of the store covered with straw in such a way as to allow air to pass out but no rain to penetrate. The thickness of soil covering will depend on the climate. In very cold conditions, soil up to 25 cm may be required to protect the crop from frost. In very hot conditions, a thick soil or organic material covering may also be necessary to prevent large temperature rises during the day. In European countries, many root crops have been traditionally stored in this way, and even apples. In the Sudan, potatoes are stored in pits with a heavy straw covering



Figure 41 Traditional potato clamp in Britain. (Source: © Ministry of Agriculture, Fisheries and Food, UK.)

for insulation. Labour requirements for construction, loading and unloading are very high and storage periods are normally short, otherwise there are high crop losses. Storage of taro corms in pits lined with leaves or plastic film extended their storage life by some 4 weeks compared to the traditional method of storing them in heaps in the shade in the South Pacific islands (Gollifer and Booth 1973).

Clamps

These have been used as a traditional method of storing potatoes and as recently as 1963, some 48% of potatoes stored in Britain were stored in clamps

(Figure 41). Since then, the proportion has reduced rapidly and the method is uncommon today. Clamps were also developed for cassava storage in Colombia (Figure 43), where successful storage for over 8 weeks was reported (Booth 1977).

The design of potato clamps in Britain varied between regions and a common design was as follows. An area of land at the side of the field was selected that was not subject to water logging. The width of the clamp usually ranges from 1 to 2.5 m and any suitable length. The dimensions are marked out and the potatoes piled on the ground in an elongated conical heap. Sometimes, straw is laid on the soil before the potatoes. The central height of the heap of potatoes depends on their angle of repose that is about one third of its width. Straw is then laid on the heap of potatoes in overlapping layers starting at the bottom and working upwards. At the top, straw is bent over the ridge so that rain will tend to run off the structure. Straw thickness should be 15–25 cm when compressed. After about 2 weeks, the clamp is covered with soil to a depth of 15–20 cm, but this may vary depending on the climate. Potatoes stored in clamps in hot climates should be of 1.5 m maximum width with a ventilating duct at ground level down the centre (Figure 42). Extra straw covering may be needed in hot climates (CIP 1981). Cassava stored in clamps for 1 month have 75% of the original weight in marketable condition with additional losses up to 3 months storage being usually small (Booth 1977).

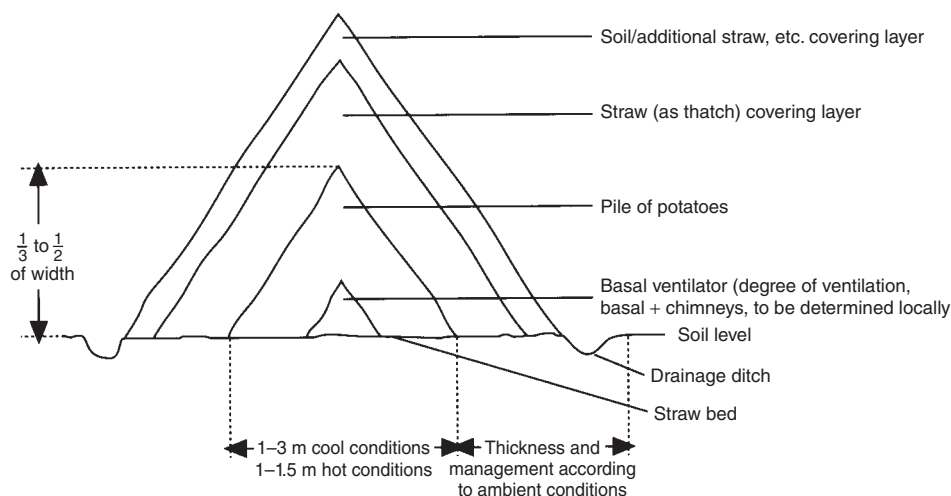


Figure 42 Diagram of a clamp designed for potato storage. (Source: CIP 1981.)

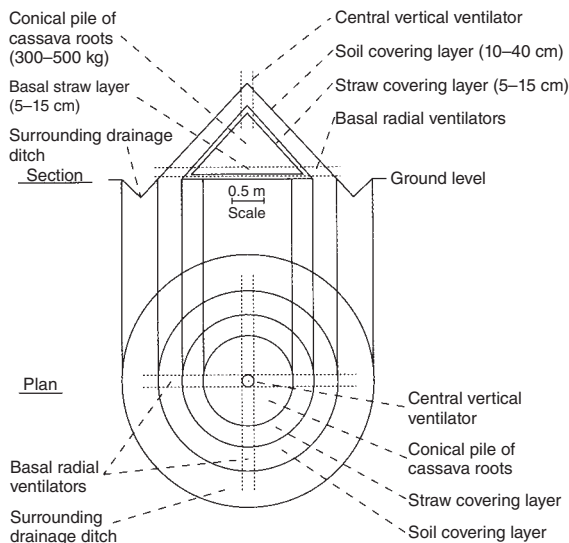


Figure 43 Diagram of a clamp designed for cassava storage. (Source: Booth 1977. Reproduced with permission of Cambridge University Press.)

Windbreaks

This is a traditional way of storing onions in Britain and farmers claim they can be stored in this way for up to 6 months. Windbreaks are constructed by driving wooden stakes into the ground in two parallel rows about a meter apart. The stakes should be slightly sloping outwards and should be about 2 m high. A wooden platform is built between the stakes about 30 cm from the ground, often made from up turned wooden boxes. Chicken wire is fixed between the stakes and across the two ends of the windbreak. The onion bulbs are then loaded into the cage, covered with 15–20 cm on straw. On top of the straw, a PE film sheet (about 125- μ m thick) is placed and weighted down with stones to protect it from the rain (Figure 44). The windbreak should be sited with its longer axis at right angles to the prevailing wind.

Cellars

These are underground or partly underground rooms often below a house. This location provides good insulation, which means they are cool in warm ambient conditions, and protected from excessively low



Figure 44 A traditional East Anglian windbreak onion store in the United Kingdom in 1976.

temperatures in cold conditions. In Britain, they were used for storing such crops as apples, cabbages, onions and potatoes during the winter. The crops were usually spread out thinly on shelves to ensure good air circulation. Onions and garlic would be plaited into bunches and suspended from hooks, a method that is commonly used throughout the world. In the mountainous regions of Nepal, cellars are dug into the sides of slopes for storing apples. In that area, night temperatures are low and the hillside provides insulation to reduce the temperature rise during the day.

Barns

Farmers build various simple structures for crop storage. In Nigeria, yams are stored in specially constructed barns (Figures 45 and 46). The traditional barn consists of a framework of raffia palm poles supported by erect stems usually of *Newbouldia laevis*, with the live plants giving a canopy to provide shade and shelter. Yams are stored in slatted wooden trays in the coastal region of Cameroon (Lyonga 1985). Ezeh (1992) described a modified design for a yam barn. It was a rectangular building with walls made of wire mesh and supported by timber pillars 10.2 $\times$ 10.2 $\times$ 3.0 m with a cement floor and the roof made of corrugated aluminium sheets; the ceiling was constructed with bamboo sticks and raffia mats. Results showed that investing in this improved storage barn in Nigeria was economically worthwhile for both long- and short-term. In the Sudan, onions are stored in barns



Figure 45 Yam barn in Nigeria showing the construction using live branches that produce leaves to provide a shaded humid environment.



Figure 46 Detail of how yam tubers are tied to the upright poles in a Nigerian yam barn.

called rakubas that are made from either mud walls with a thatched roof or palm leaves (Figure 47).

Evaporative coolers

When water evaporates from the liquid to the vapour phase, it requires energy. This principle can be used to



Figure 47 A traditional palm leaf store, called a rakuba, being used for onions in the Sudan. (Source: Sulafa Khalid Musa.)

cool stores by passing the air that is introduced into the store, first through a pad of water. The degree of cooling depends on the original humidity of the air and the efficiency of the evaporating surface. If the ambient air has low humidity and this is humidified to close to 100% r.h., then a large reduction in temperature can be achieved. This can provide cool moist conditions in the store. Both active and passive evaporative cooling systems are used. In passive systems, the cooling pads are placed over the entrances to the store and kept moist. These entrances should be in a position so that the prevailing wind can blow through them. In active stores, air is drawn into the store by a fan through a moist pad. The pad (Figure 48) can be kept moist by constantly pumping water over it. This latter type is much more efficient in cooling but does require an electricity supply. A comprehensive review of different designs of evaporative coolers is included in Bautista (1990) including their use during road transport and on small boats.

In Nigeria, the shelf life of carrots stored in a brick wall evaporative cooler was extended by 4–20 days relative to ambient storage (Babarinsa *et al.*

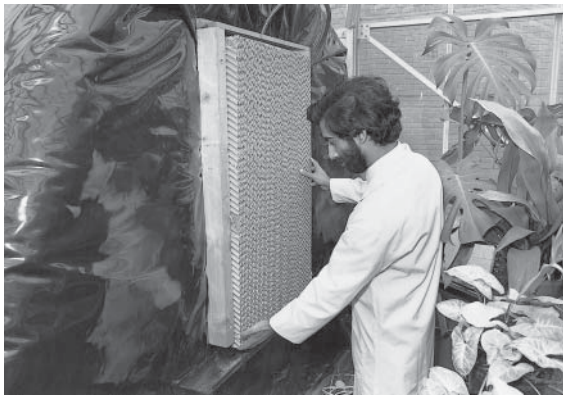


Figure 48 An experimental evaporatively cooled store at Cranfield Institute of Technology showing the constantly moistened Celdec pad through which the air is passed to cool the insulated store. (Source: A.J. Hilton. Reproduced with permission of Cranfield University.)

1997). In India, Fuglie *et al.* (2000) found that cold stores were the only viable alternative for long-term (5–8 months) storage of table and seed potatoes. However, evaporative cool stores could significantly reduce losses in farm stores for shorter-term storage, but their higher capital costs, compared to farmers' traditional methods, limit their adoption prospects among Indian potato farmers. The two evaporative cooler structures tested by Acedo (1997), one with jute sack walling and the other with a rice hull wall insert, maintained temperatures 1–6 °C lower and relative humidities 10–20% higher than ambient.

Night ventilation

In hot climates, the variation between day and night temperatures can be used to keep stores cool. The store should be well insulated and the crop is placed inside. A fan is built into the store that is switched on when the outside temperature is lower than the temperature within the store. This is at night, and when the temperatures have equalised, the fan is switched off. A differential thermostat that constantly compares the air temperature outside the store with the internal store temperature can control the fan. In a study on such a night-ventilated store, Skultab and Thompson (1992) showed that onions could be maintained at an even temperature very close to the minimum night temperature. The design that was used is shown in Figure 49. A time switch can also be

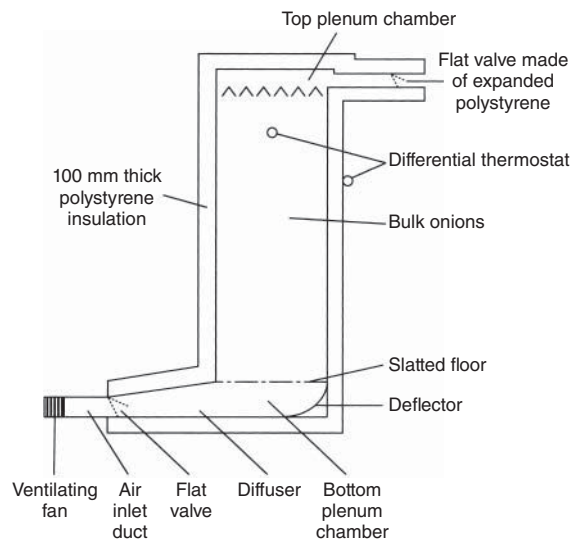


Figure 49 Diagram of a night-ventilated onion store. (Source: Skultab and Thompson 1992.)

used which would be set to, for example, switch the fan on for 2 h each day between 5.0 AM and 7.0 AM. An onion store was built and tested in the Sudan, which was, similar to that described by Skultab and Thompson (1992).

Passive night-ventilated stores have been designed, which rely on opening the store door at nights to admit the cold air and closing them during the day. Convective night-ventilated stores have been developed, which use heated rocks to draw air currents through the store at night (Bishop 1992). These latter two methods require constant manual attention.

Refrigerated storage

Generally, the lower the storage temperature for fruit and vegetables down to their freezing point, the longer the storage life. The increase in the rate of deterioration is related to the metabolic processes of the crop. Within the physiological temperature range of the crop, the respiration rate increases exponentially with temperature, so that for every 10 °C rise in temperature, the increase in metabolism is in the order of two to three times. This is called the Q_{10} value and is predicted by the Van't Hoff rule. Many crops suffer from chilling injury at temperatures well above their freezing point; therefore, it is essential to

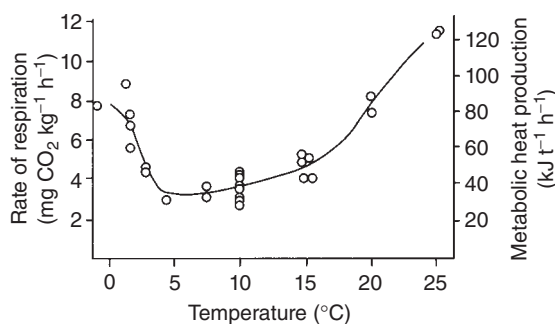


Figure 50 Respiration rate of potato tubers at various temperatures. (Source: Burton 1989.)

clearly define the temperature range over which the prediction applies. This varies not only between different crop species but also with different varieties of the same species. In some crops, storage at or just above their freezing point can greatly extend their marketable life compared to storage at 0 °C. This has been shown for crops such as pears and broccoli. In Japan, this low-temperature technology was developed in fruit and vegetable marketing to maintain a cold chain for produce of between 0 and -3 °C right through the distribution network even to the consumer's refrigerator (Anonymous 1988).

There is a relationship between temperature and respiration rates, but for some crops, the relationship is not linear. Burton (1989) showed that for potatoes, the respiration rate actually increased at lower temperatures (Figure 50). With onions, sprouting and therefore respiration of bulbs decreased with increasing temperature over the range of 15–25 °C (Karmarkar and Joshi 1941). Many crops suffer from chilling injury at temperatures well above that at which they will freeze.

Refrigeration equipment

The most effective way of achieving accurate and constant temperature control is through refrigeration of an insulated structure. Refrigeration equipment works by having pipes containing a liquid or gas (called the refrigerant) inside the store. These pipes pass out of the store; the liquid is cooled and passed into the store to reduce the air temperature of the store as it contacts the cooled pipes. A simple refrigeration unit consists of an evaporator, a compressor, a

condenser and an expansion valve. The evaporator is the pipe that contains the refrigerant mostly as a liquid at low temperature and low pressure, and is the part of the system that is inside the store. The evaporator causing the refrigerant to boil absorbs heat. The vapour is drawn along the pipe through the compressor, which is a pump that compresses the gas into a hot high-pressure vapour. This is pumped to the condenser where the gas is cooled by passing it through a radiator. The radiator is usually a network of pipes open to the atmosphere. The high-pressure liquid is passed through a series of small-bore pipes that slows down the flow of liquid so that a high pressure builds up. The liquid then passes through an expansion valve that controls the flow of refrigerant and reduces its pressure. This reduction in pressure results in a reduction in temperature causing some of the refrigerant to vaporise. This cooled mixture of vapour and liquid refrigerant passes into the evaporator so completing the refrigeration cycle. In most stores, a fan passes the store air over the coiled pipes containing the refrigerant that helps to cool the air quickly and distribute it evenly throughout the store. The fan gives out heat, which is undesirable, and studies on methods of eliminating the fan in cold stores have been undertaken (Robinson 1990). The basis of these studies was to use convective currents caused in the store by heat given out by the crop and the cooled air from the coils of refrigerant pipes to maintain an even temperature throughout the store. The amount of heat absorbed by the cooling coils is related principally to the temperature of the refrigerant they contain and the surface area of the coils.

Humidity control

In order to maintain the quality of stored fruit and vegetables, they are normally kept in humid conditions. For most crops, the higher the humidity, the better. However, if the humidity is too high in a refrigerated store, water may condense on the crop surface and increase rotting. In some cases, low humidity can increase rotting (Thompson 1972a, 1972b). Also in studies where kiwifruit were stored at 0 °C with 40–59%, 65–80% or 92–97% by Bautista-Baños *et al.* (2000), it was found that the overall general pattern showed that with an increase in humidity, infection levels decreased. The temperature differential between the evaporator refrigerant

Table 19 Approximate effects on store humidity of the temperature differential between the evaporator refrigerant and the store air

Temperature differential (°C)		Relative humidity (%)
Natural convection	Air circulation by a fan	
7–8	4–6	91–95
8–9	6–7	86–90
9–10	7–8	81–85
10–11	8–9	76–80
11–12	9–10	70–75

and the store air determines the moisture content of the store air (Table 19).

If the refrigerant temperature is low compared to the store air temperature, then water will condense on the evaporator. If the refrigerant is below 0 °C, ice will be formed over the cooling coils making them less efficient in cooling the store air. This removal of moisture from the store air reduces its relative humidity and increases its vapour pressure deficit. This means that the stored crop will lose water more quickly, which can adversely affect its marketability. In order to reduce crop desiccation, the refrigerant temperature should be kept close to the store air temperature. However, with respiratory heat from the crop, temperature leakage through the insulation and doors and heat generated by fans, it may not be possible to maintain the store temperature. There remains the possibility of increasing the area of the cooling surface and adding such devices as fins to the cooling pipes or coiling them into spirals. In a study of an apple cold store design in New Zealand on the humidity of the air, Amos *et al.* (1993) found that the evaporated surface area and the occurrence of precooling within the store were the design and operational factors having the greatest effect on the relative humidity of the air. Door protection and management and floor insulation were the next most significant effect on relative humidity, but close stacking of storage bins could have the reverse effect.

A study on evaporator coil refrigerant temperature, room humidity, cool-down and mass loss rates was carried out by Hellickson *et al.* (1995) in commercial 1200-bin apple storage rooms. Rooms, in which the evaporator coil ammonia temperatures were dictated by cooling demand, required a significantly longer time to achieve desired humidity levels than rooms in which evaporator coil temperatures were controlled

by a computer. The overall mass loss rate of apples stored in a room in which the cooling load was dictated by refrigerant temperature was higher than in a room in which refrigerant temperature was maintained at approximately 1 °C during the fruit cool-down period.

Another device is to have secondary cooling so that the cooling coils do not come into direct contact with the store air. One such system is the 'jacketed store'. These stores have a metal inner wall inside the store's insulation with the cooling pipes cooling the air in that space. This means a low temperature can be maintained in the cooling pipes without causing crop desiccation and the whole wall of the store becomes the cooling surface. Ice bank cooling is also a method of secondary cooling, where the refrigerant pipes are immersed in a tank of water so that the water is frozen. The ice is then used to cool water and the water is converted to a fine mist that is used to cool and humidify the store air (Lindsey and Neale 1977, Neale *et al.* 1981).

A whole range of humidifying devices can also be used to replace the moisture in the air, which has been condensed out on the cooling coils of refrigeration units. These include spinning disc humidifiers, where water is forced at high velocity onto a rapidly spinning disc. The water is broken down into tiny droplets that are fed into the air circulation system of the store. Sonic humidifiers utilise energy to detach tiny water droplets from a water surface that are fed into the stores' air circulation system. Dijkink *et al.* (2004) described a system that could maintain relative humidity very precisely in 500-L containers. For example, they were able to maintain $90.5 \pm 0.1\%$ r.h. using a hollow fibre membrane contactor that allowed adequate transfer of water vapour between the air in the storage room and a liquid desiccant. The membrane was made of polyetherimide coated on the inside with a thin non-porous silicone layer. The desiccant was a dilute aqueous glycerol solution that was pumped through the hollow fibres at a low flow rate.

Solar-driven refrigerated stores

Since part of the refrigeration cycle requires the input of energy, there has been interest in tropical countries in using the sun to provide this energy. One such project was developed in the Sudan by technical cooperation between the Sudanese and Dutch

Governments (Anonymous 1990). The store had a single stage ammonia/water absorption refrigerator with 13-kW peak cooling power, which was designed to keep 10 tonnes of agricultural products at a minimum temperature of 5 °C. The 50 m³ was constructed and tested on bananas, grapefruit, onions and potatoes. The project in the Sudan proved not to be cost-effective when compared to a conventional cold store operated from mains electricity. The price of electricity would have to increase by a factor of 10 before the solar-driven cold store could compete with grid-driven compressor systems.

Solar voltaic cells have been available for decades, but again suffer from the same problem as described above, which is that there are cheaper sources of energy. They have had some limited practical use in developing countries where they have been used to power small portable refrigerators for keeping medicines in remote areas where there is no main electricity. However, Umar (1998) claimed that solar cooling systems can be used to preserve food in rural locations in tropical countries either by the production and distribution of ice or by the provision of large cold stores for community use.

Controlled atmosphere stores

Controlled atmosphere is still mainly applied to stored apples, but studies of other fruit and vegetables have shown it has wide application. Commercial practice can be basically the same as that described in the early part of the 20th century. Factors to be taken into account with controlled atmosphere storage include:

1. It is expensive; therefore, only the best fruit should be stored.
2. If there is a choice, small fruit should be stored, as it has been found in apples that they store better than large fruit.
3. Fruit should be placed in storage as soon as possible after harvest and in any case within a day.
4. The store should be closed and cooled each evening during loading.
5. Loading should be as quick as possible and certainly within 1 week.
6. For apples, at whatever subsequent temperature they are to be stored, the fruit should be initially cooled to 0 °C.

7. Only one type of crop should be stored in the same room and preferably only one cultivar.

History

The effects of gases on harvested crops have probably been known for centuries. In eastern countries, fruits were taken to temples, where incense was burned, to improve ripening. In Britain, crops were stored in pits which would have restricted ventilation and thus affected the O₂ and CO₂ levels in the pit. The earliest documented scientific study was by J. E. Bernard in 1819 in France, who showed that harvested fruit absorbed O₂ and gave out CO₂. He also showed that fruit stored in atmospheres containing no O₂ did not ripen, but if they were held for only a short period in zero O₂ and then placed in air, they continued to ripen. These experiments showed that storage in zero O₂ gave a life of 28 days for peaches, prunes and apricots and until 3 months for apples and pears. In 1856, B. Nice built a commercial cold store using ice to keep it below 1 °C. A decade later, he experimented with modifying the CO₂ and O₂ in the store by making it air tight. This was achieved by lining the store with metal sheets, thickly painting the edges of the metal and having tightly fitted doors. It was claimed that 4000 bushels of apples were kept in good condition in the store for 11 months, and that the O₂ level in the store was so low that a flame would not burn. J. Fulton in 1907 observed that fruit could be damaged where large amounts of CO₂ were present in the store. R. W. Thatcher in 1915 experimented with apples sealed in boxes containing different levels of gases and concluded that CO₂ greatly inhibited ripening. Kidd (1916) described the effects of different concentrations of CO₂ on the respiration of seeds. Kidd and West (1917) carried out comprehensive studies on CO₂ and O₂ on fruit and vegetables and called the technique gas storage (Kidd and West 1927). The modern application of the manipulation of gases in crop stores on a commercial basis can be traced to their work. In the early 1940s, the term *gas storage* was replaced by controlled atmosphere storage, and it has been the subject of an enormous number of studies, in spite of which, it is still not known precisely why it works. A current hypothesis is that the success of controlled atmosphere storage is the result of a stress response, but the mechanism is still unknown (J.R. Stow 2002, personal communication).

The effect that O_2 and CO_2 have on crops varies with such factors as the species and cultivar of crop, the concentration of the gases, the crop temperature and its stage of maturity or ripeness. There are also interactive effects of the two gases, so that the effect of the CO_2 and O_2 in extending the storage life of a crop may be increased when they are combined.

Oxygen reduction

The crop is loaded into an insulated storeroom, whose walls have been made gas tight. The time taken for the levels of these two gases to reach the optimum (especially for the O_2 to fall from the 21% in normal air) can reduce the maximum storage life of the crop. It is common therefore to fill the store with the crop, seal the store and inject nitrogen gas until the O_2 has reached the required level and then maintain it in the way described below. The nitrogen may be obtained from large liquid nitrogen cylinders. Malcolm and Gerdtz (1995) in a review described three main methods used to produce nitrogen gas used for controlled atmosphere applications. These were cryogenic distillation, pressure swing adsorption system and membrane systems. Hollow fibre technology is also used to generate nitrogen to inject into the store (Figure 51). The walls of these fibres are differentially permeable to O_2 and nitrogen. Compressed air is introduced into these fibres, and by varying the pressure, it is possible to regulate the purity of the nitrogen coming out of the equipment and produce an output of almost pure nitrogen. Another type of nitrogen generator

is called pressure swing adsorption. This has an air compressor that passes the compressed air through a molecular sieve that traps the O_2 in the air and allows the nitrogen to pass through. It is a dual circuit system so that when one circuit is providing nitrogen for the store, the other circuit is being renewed. The O_2 content at the output of the equipment will vary with the throughput. For a small machine with a throughput of $5 \text{ nm}^3 \text{ h}^{-1}$, the O_2 content will be 0.1%; at $10 \text{ nm}^3 \text{ h}^{-1}$, it will be 1% and at $13 \text{ nm}^3 \text{ h}^{-1}$, it will be 2% (Thompson 1996). In China, a carbon molecular sieve nitrogen generator has been developed (Shan Tao and Liang 1989). This was made from fine coal powder that was refined and formed to provide apertures similar to the size of a molecule ($3.17 \text{ \AA}$) but smaller than an O_2 molecule ($3.7 \text{ \AA}$). When air was passed through the carbon molecular sieve under high pressure, the O_2 molecules were absorbed onto the carbon molecular sieve and the air passing through has an enriched nitrogen level. A pressurised water CO_2 scrubber was described by Vigneault and Raghavan (1991), which could reduce the time required to reduce the O_2 content in a controlled atmosphere store from 417 to 140 h.

Carbon dioxide enrichment

For crops that have only a very short marketable life, such as strawberries, the CO_2 level may also be increased to the required level by direct injection of CO_2 from a pressurised gas cylinder. This is particularly important where controlled atmospheres are used in transport.

Dynamic controlled atmosphere

In DCA storage, the level of gases is monitored on the basis of the physiology of the fruit or vegetable and data are passed to the control mechanism that then adjusts the atmosphere in the store. A link between the minimum fluorescence (F_o) and a metabolic shift from predominantly aerobic to fermentative metabolism (the lower O_2 limit) is the foundation of DCA (Wright *et al.* 2012).

Thompson (2010) reported that in some CA stores in England, where they stored apples in 1% O_2 , an alcohol detector was fitted which sounded an alarm if ethanol fumes were detected because of fermentation (anaerobic respiration). This enabled



Figure 51 Nitrogen generator used to rapidly reduce O_2 levels in controlled atmosphere stores.

the store operator to increase the O_2 level and no damage should have been done to the fruit. The detector technology was based on that used by the police to detect alcohol fumes on the breath of motorists. This technology was subsequently developed and Schouten (1997) described a system which he called dynamic control of ultra low oxygen storage based on headspace analysis of ethanol levels that were maintained at less than 1 ppm where O_2 levels were maintained at 0.3–0.7% in the store. This can be detected in store and the O_2 adjusted to just above the threshold level for fermentation. A more recent method of dynamic controlled atmosphere storage uses other stresses associated with metabolic responses of fruit and vegetables to low O_2 levels. Therefore, DCA uses the responses of actual fruit or vegetable being stored as monitors of the store atmosphere. The stress is detected and the storage atmosphere is adjusted to relieve this stress, usually a computer programme is used which maintains the level of O_2 at slightly above the stress level. It has been claimed that DCA has allowed lower levels of O_2 to be used that may extend the postharvest life (DeLong *et al.* 2004). A commercial technology based on chlorophyll fluorescence measurement of stress which occurs when there is insufficient O_2 for aerobic metabolism has been patented and commercialised and is called HarvestWatchTM. DeLong *et al.* (2004) indicated that HarvestWatch facilitated ‘what may be the highest possible level of fruit quality retention in long-term, low-oxygen apple storage without the use of scald-controlling or other chemicals before storage’.

Burdon *et al.* (2008) reported that after DCA storage, using chlorophyll fluorescence, Hass avocados ripened in 4.6 days at 20 °C compared with 7.2 days for ‘static’ CA stored fruit and 4.8 days for fruit stored throughout in air. They also stored Hass in DCA (<3% O_2 + 0.5% CO_2) for 6 weeks at 5 °C and compared it to static CA in 5% O_2 + 5% CO_2 . Chlorophyll fluorescence was also measured and found to occur in Hass, which remained constant at 0.8 at 6 °C in O_2 levels down to 1%, but below that, it rapidly dropped to 0.68 within 24 h. When the fruit were kept for 6 days and then returned to non-stressed atmosphere, the chlorophyll fluorescence rapidly returned to 0.8. At 6 °C, CO_2 above 5% resulted in a slight reduction in chlorophyll fluorescence, which again returned to 0.8 when the fruit were returned to levels below 5%.

The effect was more marked at 0 °C (Yearsley *et al.* 2003). Earlier work showed that chlorophyll fluorescence changes of broccoli were associated with the accumulation of CO_2 in MA packages during storage (Toivonen and DeEll 2001). They also found that chlorophyll fluorescence was highly correlated with the anaerobic volatile content and off-odours in broccoli during longer storage durations in MA packaging.

In other work, the respiration rate characteristics of fruit or vegetables (CO_2 evolution, O_2 consumption, ethanol accumulation, etc.) were fitted to a polynomial equation used in the ‘Response Surface Methodology’ and tested on cherry tomatoes in order to determine optimum CA storage conditions. The regression equations fitted well with the experimental data of the respiration characteristics having a coefficient of determination $R^2 > 0.8$ and the effective CA conditions for cherry tomatoes were estimated at 4–6% O_2 + 3.5–10% CO_2 . Under these conditions, their storage quality and sensory evaluation were satisfactory without CO_2 injury and/or development of off-flavours (Lee *et al.* 2003).

The incidences of stem end rot, body rot and vascular browning of avocados were lower in DCA stored fruit (35, 29 and 29%, respectively) than in ‘standard CA’ stored fruit (57, 52 and 49%, respectively), or fruit stored in air (76, 88 and 95%, respectively) (Burdon *et al.* 2008). Fruit firmness of DCA stored apples was in general significantly higher than those of ULO stored fruit after storage for about 200 days (Gasser *et al.* 2008).

The anaerobic compensation point (ACP) is the critical internal O_2 concentration where the fruit or vegetable metabolism reaches a level that results in fermentation and is applied during DCA. Two methods of detecting the ACP were described by Gasser *et al.* (2008) based on respiratory quotient and fluorescence signal Fa monitoring which were used to detect the critical O_2 concentration during DCA storage. DCA under a stress atmosphere maintains a flat fluorescence (Fa) baseline whereas those with lower O_2 produce a Fa spike. O_2 -induced fluorescence shifts occurred quickly at the lower O_2 limit of the fruit or vegetable and were measurable and returned quickly to its prestressed level when the O_2 was raised above the lower O_2 limit (Wright *et al.* 2009). Chávez Franco *et al.* (2004) calculated the mean ACP values for Hass avocados as

1.44% at 5.5 °C and 1.81% at 20 °C. These values increased with ripening, and they claimed that their results could be used to define appropriate storage conditions for Hass avocado fruits in MA systems. The production of fermentation metabolites was not exclusive to O₂ concentrations below the ACP, and temperature affected the accumulation of these compounds, with values of 10.7 mol 100 ml L⁻¹ at 5.5 °C and 101.3 mol 100 ml L⁻¹ at 20 °C. The production of those metabolites significantly increased with ripening and the values were, in the post-climacteric stage, 20 and 39 times greater than in the preclimacteric one, at 5.5 and 20 °C, respectively. Braeburn with 0.4% O₂ exhibited a higher critical level of ACP than Golden Delicious, Elstar and Maigold, which were 0.25–0.30%. After the critical O₂ limit was reached, the O₂ concentration was increased by about 0.1–0.3% above the critical limit. In this way, fruits were held for 200 days at O₂ levels of 0.3–0.6% without causing physiological disorders (Gasser *et al.* 2008). In storage at 7–9 °C, Fonseca *et al.* (2004) found that Royal Sweet watermelons had a higher respiration rate at 8% O₂ compared to 14% O₂, indicating that they have a high ACP.

Wright *et al.* (2012) reported that currently DCA technology uses pulse frequency-modulated sensors and employs a range of light intensities and extrapolation to measure *Fa*, an approximation of *Fo*. Like fruit mass, colour, sugar or acid levels, the lower O₂ limit is inherently variable even from a given cultivar and tree or between the sun-exposed and shaded regions of a single fruit. They suggested the low O₂-induced rise in *Fa* results from a shutdown of mitochondrial function and a build-up of reductant that leads to an over-reduction of the plastoquinone (PQ) pool and a decrease in photochemical quenching. Hypoxic conditions above the lower oxygen limit can decrease *Fa* slightly in some species, possibly as a result of zeaxanthin formation and increased non-photochemical quenching. Low-intensity light differentially affects *Fa* depending on the O₂ level: light increases *Fa* when O₂ levels are above the lower oxygen limit due to light-induced reduction of the oxidised PQ pool, but decreases the elevated *Fa* signal below the lower oxygen limit as a result of a PSI-driven oxidation of the over-reduced PQ pool. Temperature has a negative, primarily non-physiological correlation with the *Fa* baseline that seems unrelated to the PQ pool redox state.

Controlled atmosphere controls

The temperature in the storeroom is controlled by mechanical refrigeration and the composition of the atmosphere is constantly analysed for CO₂ and O₂ levels. When the O₂ has reached the level required for the particular crop being stored, it is maintained at that level by frequently introducing fresh air from outside of the store. Usually tolerance limits are set at, say plus or minus 0.1%, so that when the O₂ level is 0.9%, air is vented until it reaches 1.1%. The same applies to CO₂. When a predetermined level is reached, the atmosphere is passed through a chemical that removes CO₂ and then back into the store. This is called active scrubbing. Alternatively, the CO₂-absorbing chemical may be placed inside the store where it can keep the level low (usually about 1%) and is called passive scrubbing. This method of controlled atmosphere store is referred to as *product generated*, as the gas levels are produced by the crops respiration. The time taken for the levels of these two gases to reach the optimum (especially for the O₂ to fall from the 21% in normal air) can reduce the maximum storage life of the crop. It is common therefore to fill the store with the crop, seal the store and inject nitrogen gas until the O₂ has reached the required level and then maintain it in the way described above.

Controlled atmosphere storage on aroma and flavour

Controlled atmosphere storage increases the postharvest life of crops and there has been concern that extended storage may adversely affect the eating qualities (Blythman 1996). Many experiments have been carried out to test the effects of controlled atmosphere storage on fruit and vegetable quality and results have been variable. Aroma volatiles in Golden Delicious apples were suppressed during storage at 1 °C for up to 10 months in atmospheres containing high levels of CO₂ (3%) or low levels of O₂ (1 or 3%) compared to storage in air (Brackmann 1989). The measurement of the organic volatile production of the apples was over 10-day period at 20 °C after removal from the cold store. In McIntosh and Cortland apples, most organic volatile compounds were produced at lower rates during ripening after controlled atmosphere storage than those produced from fruits ripened immediately after harvest (Yahia 1989).

Table 20 Effect of controlled atmosphere storage on the acidity and firmness of Spartlett pears stored at 0 °C and their taste after 7 days of subsequent ripening at 20 °C (source: adapted from Meheriuk 1989)

Storage atmosphere		Storage time (days)	Acidity (malic acid mg 100 ml ⁻¹)	Taste (score 1 = like, 9 = dislike)	Firmness (Newtons)
CO ₂ (%)	O ₂ (%)				
0	21	60	450b	6.1	62a
5	3	60	513a	7.6	61ab
2	2	60	478ab	7.6	60b
0	21	120	382b	4.3	55b
5	3	120	488a	6.7	58a
2	2	120	489a	6.9	58a
0	21	150	342b	2.9	51b
5	3	150	451a	7.7	58a
2	2	150	455a	7.1	58a
0	21	180	318b	—	40b
5	3	180	475a	—	62a
2	2	180	468a	—	61a

Figures followed by the same letter were not significantly different ($p = 0.05$) by the Duncan's multiple range test.

Storage of pears in controlled atmosphere conditions did not have a deleterious effect on fruit flavour compared to those stored in air and were generally considered better (Meheriuk 1989). However, controlled atmosphere storage generally resulted in significantly higher acid levels in fruit (Table 20). Litchis fruit were packed in punnets and stored in air or overwrapped with plastic film with 10% CO₂ or vacuum packed. They were then stored for 28 days at 1 °C followed by 3 days shelf life at 20 °C. It was found that their taste and flavour of the fruit from both the plastic film packs were unacceptable, while they remained acceptable for the non-wrapped fruits (Ahrens and Milne 1993).

Oxygen effects

Many chemical reactions in crops are catalysed by enzymes and the reactions require molecular O₂. Therefore, as O₂ levels in plant cells fall, the rate of chemical reactions decrease and metabolism is reduced. This effect tends to be accelerated at very low levels of O₂. If the O₂ level in the cells is too low, there may be undesirable changes in the chemicals that contribute to the flavour and aroma of the crop. At very low levels of O₂, the tricarboxylic acid cycle is inhibited but the glycolytic pathway may continue. This results in less efficient energy production during respiration as there is insufficient O₂ to metabolise stored carbohydrates to water and CO₂. Instead,

the blocking of the glycolytic pathway results in a build-up of acetaldehyde and ethanol, which are toxic to the cells if allowed to accumulate. The amount of O₂ in the cells is proportional to:

- the O₂ level surrounding the crop
- the permeability of the crop surface
- the diffusion of O₂ through the crop
- temperature of the crop
- innate metabolic rate of the crop.

Robinson *et al.* (1975) studied the respiration rate of a variety of crops at different temperatures stored in air or in 3% O₂. Respiration was generally lower when crops were stored in 3% O₂ than when they were stored in air, but there were some interactions between O₂ and temperature in that the effects of the reduced O₂ level was more marked at higher storage temperatures.

The effect that low O₂ has on the crop also depends on the duration of exposure. Ke and Kader (1989) showed that fruits such as pears, stone fruit, blueberries and strawberries stored at between 0 and 5 °C for up to 10 days would tolerate O₂ levels of between 0.25 and 1%, whereas apples could tolerate these levels for longer periods. Detrimental effects of low O₂ on the crop include the accumulation of ethanol and acetaldehyde to concentrations that can result in off-flavours (Ke and Kader 1989). The level of O₂ at which anaerobic respiration may occur in plant cells may be as low as 0.2%, but the gradient

Table 21 The effects of oxygen on postharvest responses of fruit, vegetables and flowers

Reduced respiration rate
Reduced substrate oxidation
Delayed ripening of climacteric fruit
Prolonged storage life
Delayed breakdown of chlorophyll
Reduced rate of production of ethylene
Changed fatty acid synthesis
Reduced degradation rate of soluble pectins
Formation of undesirable flavours and odours
Altered texture
Development of physiological disorders

of O₂ concentration between the store atmosphere and the cells of the crop requires the maintenance of a higher level around the crop (Kader 1986). The gradient is affected by the ease of gas penetration through the cells and cuticle or periderm of the crop and the utilisation of O₂ by the crop. In modern controlled atmosphere apple stores where they are stored at 1% O₂, an alcohol detector is fitted which sounds an alarm if ethanol fumes are detected in the store. This enables the store operator to increase the O₂ level and no damage should have been done to the fruit. The detector technology is based on that used by the police to detect alcohol fumes on the breath of motorists. It has been shown that low O₂ levels in store can affect the crop in several ways (Richardson and Meheriuk 1982). These are summarised in Table 21.

Carbon dioxide effects

The effect of CO₂ in extending the storage life of crops appears to be on reduction in respiration of the crop. Knee (1973) showed that CO₂ could inhibit an enzyme (succinate dehydrogenase) in the tricarboxylic acid, which is part of the crop's respiratory pathway. The atmosphere inside the tissue of the crop will equalise with the atmosphere in the store if it is at the same temperature and pressure. Where the level of CO₂ in the store is increased, this will therefore increase its levels within the crop tissue (Table 22).

It was suggested that high levels of CO₂ in stores could compete with ethylene for binding sites in fruits (Burg and Burg 1967). They showed that in the presence of 10% CO₂, the biological activity of 1% ethylene was abolished. Yang (1985) showed that CO₂

Table 22 The effects of CO₂ on postharvest responses of fruit, vegetables and flowers

Decreased synthetic reactions in climacteric fruit
Delaying the initiation of ripening
Inhibition of some enzyme reactions
Decreased production of some organic volatiles
Modified metabolism of some organic acids
Reducing the rate of breakdown of pectic substances
Inhibition of chlorophyll breakdown
Production of 'off-flavours'
Induction of physiological disorders
Retarded fungal growth on the crop
Inhibition of the effect of ethylene
Changes in sugar content (potatoes)
Effects on sprouting (potatoes)
Inhibition of postharvest development
Retention of tenderness
Decreased discoloration levels

accumulation in the intercellular spaces of fruit acts as an ethylene antagonist.

Physiological disorders in fruit associated with excess CO₂ levels may be associated with this disruption of the respiratory pathway, leading to an accumulation in the crop cells of alcohol and acetaldehyde. The sensitivity of crops to CO₂ varies widely. This may be related to the permeability of the crop tissue to gas exchange (intercellular spaces, cuticle thickness and composition, presence of stomata, lenticels and hydrothodes and the nature of the cell tissue), which could affect the level of CO₂ in the crop cells.

Intermittent exposure of crops to high levels of CO₂ may have beneficial effects. Marcellin and Chaves (1983) showed that exposing avocado fruit to 20% CO₂ for 2 days each week in storage at 12 °C delayed their senescence and reduced decay compared to fruit stored for 7 days a week in air. They also showed that the same CO₂ treatment of fruit stored at 4 °C reduced symptoms of chilling injury.

High levels of CO₂ (10–15%) can control grey mould in grapes for limited periods. Prolonged exposure to these levels can damage the fruit, but up to 2 weeks' exposure did not have a detrimental effect (Kader 1989). Strawberries stored in high concentrations of CO₂ had reduced levels of decay (Table 23) without damaging the fruit.

Exposing grapefruit to 10–20% CO₂ can reduce chilling injury during subsequent storage at 7–10 °C (Hatton and Cubbedge 1977). Exposure to 60–90%

Table 23 The effects of carbon dioxide concentration during storage for 3 days at 5 °C on the levels of decay in strawberries and the development of decay when removed to ambient conditions (source: adapted from Harris and Harvey 1973)

Storage	CO ₂ (%)			
	0	10	20	30
3 days storage at 5 °C	11	5	2	1
+1 day at 15 °C in air	35	9	5	4
+2 days at 15 °C in air	64	26	11	8

CO₂ for 24 h at 17–20 °C removed astringency in persimmon (Ben Arie and Guelfat Reich 1976).

Physiological disorders associated with high CO₂ include:

Apples	Brown heart	Kidd and West (1923)
Apples	Core flush	Lau (1983)
Apples	Low-temperature breakdown	Fidler (1968)
Broad bean	Pitting	Tomkins (1965)
Broccoli	Accelerated softening	Lipton and Harris (1974)
Broccoli	Off-flavours	Lipton and Harris (1974)
Cabbage	Internal browning	Isenburg and Sayle (1969)
Capsicums	Internal browning	Morris and Kader (1977)
Kiwi fruit	Off-flavours	Harman and McDonald (1983)
Lettuce	Brown stain	Stewart and Uota (1971)
Mushrooms	Cap discoloration	Smith (1965)
Potato	Curing inhibition	Butchbaker <i>et al.</i> (1967)
Spinach	Off-flavours	McGill <i>et al.</i> (1966)
Strawberry	Off-flavours	Couey and Wells (1970)
Tomato	Uneven ripening	Morris and Kader (1977)
Tomato	Surface blemishes	Tomkins (1965)

Nitrogen effects

Placing fruit and vegetables in total nitrogen results in anaerobic respiration, but exposure for short periods can have beneficial effects. Treatment of tomato fruits before storage in atmospheres of total nitrogen was shown to retard their ripening (Kelly and Saltveit 1988), but they could be ripened normally when removed to a normal atmosphere. Similar effects were shown with avocados by Pesis *et al.* (1993).

Carbon monoxide

It is a colourless, odourless gas that is flammable and explosive in air at concentrations between 12.5 and 74.2%. It is extremely toxic to animals with haemoglobin and exposure by human beings to 0.1%

for 1 h can cause unconsciousness and for 4 h death. However, it can have beneficial effects in crop storage. If added to controlled atmosphere stores, with levels of O₂ between 2 and 5%, carbon monoxide can inhibit discoloration of lettuce on the cut butts or from mechanical damage on the leaves. Concentrations in the range of 1–5% carbon monoxide were effective, but the effect was lost when the lettuce was removed to normal air at 10 °C. The respiration rate of lettuce was reduced during a 10-day storage period at 2.5 °C when carbon monoxide was added to the store. A combination of 4% O₂, 2% CO₂ and 5% carbon monoxide was shown to be optimum in delaying ripening and maintaining good quality of mature green tomatoes stored at 12.8 °C after being subsequently ripened at 20 °C (Morris *et al.* 1981). In peppers and tomatoes, the level of chilling injury symptoms could be reduced, but not eliminated when carbon monoxide was added to the store.

The addition of carbon monoxide in a store can partially reduce the detrimental effects of ethylene in causing russet spotting on the leaves (Kader 1987). The reduction in respiration rate of vegetative tissue in the presence of 1–10% carbon monoxide was reversed in climacteric fruit. In tomatoes, carbon monoxide was found to stimulate respiration rate, but this effect could be minimised by reducing the level of O₂ in the store to below 5% (Kader 1987).

Carbon monoxide has fungistatic properties especially when combined with low O₂ (Kader 1983). *Botrytis cinerea* on strawberries was reduced where the carbon monoxide level was maintained at 5% or higher in the presence of 5% O₂ or lower. Decay in stored mature green tomatoes stored at 12.8 °C was reduced when 5% carbon monoxide was included in the storage atmosphere (Morris *et al.* 1981). Carbon monoxide is an analogue of ethylene and it was shown to initiate ripening of bananas when the fruit were exposed to concentrations of 0.1% for 24 h at 20 °C.

Ozone

Ozone (O₃) is a powerful oxidizing agent that has a penetrating odour and is unstable at room temperature. It is a highly toxic gas to human beings and exposure to concentrations in excess of 0.1 µL L⁻¹ should be avoided. Information on its use on fruits and vegetables is often contradictory. It has been shown that fungal growth and rotting can be controlled in

some vegetables and fruit exposed to $1\text{--}2\ \mu\text{L L}^{-1}$. Its effectiveness is increased with high humidity in the store. However, there is evidence that it is phytotoxic and peaches were damaged by exposure to $1\ \mu\text{L L}^{-1}$ O_3 and lettuce and strawberries by exposure to $0.5\ \mu\text{L L}^{-1}$ O_3 . The rate of decomposition to O_2 is rapid.

Valencia oranges were exposed continuously to $0.3 \pm 0.05\ \mu\text{L L}^{-1}$ O_3 at 5°C for 4 weeks. Eureka lemons were exposed to an intermittent day–night ozone cycle with $0.3 \pm 0.01\ \mu\text{L L}^{-1}$ O_3 only at night, in a commercial cold storage room at 4.5°C for 9 weeks. Also both oranges and lemons were continuously exposed to $1.0 \pm 0.05\ \mu\text{L L}^{-1}$ O_3 at 10°C in an export container for 2 weeks. Exposure to O_3 did not reduce final incidence of green or blue mould (*Penicillium digitatum* and *P. italicum*) on inoculated fruit, although incidence of both diseases was delayed about 1 week and infections developed more slowly under O_3 . Sporulation was prevented or reduced by O_3 without noticeable phytotoxicity to the fruit (Palou *et al.* 2001). Ozone treatment at $40\text{--}60\ \text{nl L}^{-1}$ during storage for up to 6 months at 0.5°C and $>95\%$ r.h. may be useful for reducing nesting caused by *Sclerotinia sclerotiorum* in carrots (Hildebrand *et al.* 2008). Ozone treatment of mushrooms at $100\ \text{mg h}^{-1}$ for up to 25 min before packaging PVC plastic film caused an increase in external browning rate and a reduction of the internal browning rate during 7 days subsequent storage at 5 , 15 or 25°C (Escriche *et al.* 2001). The O_3 treatment had no significant differences in terms of texture, maturity index and weight loss of mushrooms. Button mushrooms, broccoli, seedless cucumbers, lettuce, cauliflower, green pepper, apple cultivars Empire and Delicious and pear cultivars Anjou and Bosc were stored at $2\frac{1}{2}\text{--}3\frac{1}{2}^\circ\text{C}$ and ethylene levels of 1.5 and $2\ \mu\text{L L}^{-1}$, with or without ozone at $0.04\ \mu\text{L L}^{-1}$. Broccoli floret opening was better under ozone treatment compared to the control. Cut surface browning was observed in ozone-treated broccoli. Ozone extended the storage life of cucumbers. Ozone reduced the ethylene level in the apple and pear storage rooms (Skog and Chu 2001).

Ethylene

Ethylene (C_2H_4), which was discovered in 1796, was originally called olefiant gas. It should more correctly be called ethene but modern commercial use favours the term ethylene. It can be produced

by heating a mixture of one measure of ethanol with two measures of sulphuric acid. It is a colourless gas with a sweetish odour and taste, has asphyxiant and anaesthetic properties and is flammable. Physical characteristics include:

Molecular weight	28.05
Vapour pressure (9.9°C)	5.1 bar(g)
Specific volume (20°C , 1 atm.)	$861.5\ \text{ml g}^{-1}$
Boiling point (1 atm.)	-103.7°C
Freezing point (1 atm.)	-169.5°C
Density of gas (at 0°C , 1 atm.)	$1.26\ \text{g ml}^{-1}$
Flammable limits in air	$3.1\text{--}32\% \text{ v/v}$
Autoignition temperature	543°C
Specific gravity (air = 1)	0.974

Ethylene was known to have physiological effects on crops, but Gane (1934) first identified it as a volatile chemical produced by ripening apples. It was assumed that ethylene was produced only in climacteric fruits during the ripening phase, but with the development of chromatographic analytical techniques, it is clear that all crops are able to produce ethylene under certain conditions (Hulme 1971, Roberts and Tucker 1985). Microorganisms that attack stored crops can also produce ethylene.

The effects of introducing ethylene to the store on climacteric fruits are to initiate them to ripen if the:

- concentration of the gas is above the required threshold
- temperature of the fruit is within a certain range
- exposure time is sufficient
- level of other gases in the store is conducive.

Ethylene may also hasten the ripening processes of climacteric fruit after they have been initiated to ripen. It can also affect non-climacteric fruit, flowers and all types of vegetables. It is synthesised in plant tissue and its biosynthesis in fruit is related to O_2 levels. The rate of ethylene production by apples was shown to be about half in an atmosphere of $2.5\% \text{ O}_2$ compared to fruit stored in air (Burg and Burg, 1962). CO_2 levels in store affected ethylene biosynthesis. It was shown that increased levels of CO_2 in controlled atmosphere stores containing apples reduced ethylene levels (Tomkins and Meigh 1968). The sensitivity of plant tissue to ethylene has been shown to be affected by O_2 and CO_2 levels in the store (Table 24). The effects of exogenous ethylene on the tissue of plants are variable, but it has been shown to affect the rate of respiration of crops (Table 25).

Table 24 Sensitivity (concentration of ethylene causing half maximum inhibition of growth of etiolated pea seedlings at 20 °C) of pea seedlings to ethylene in different levels of oxygen, carbon dioxide and nitrogen (source: adapted from Burg and Burg 1967)

Storage atmosphere (%)			Ethylene sensitivity ($\mu\text{L L}^{-1}$)
N ₂	O ₂	CO ₂	
99.3	0.7	0	0.6
97.8	2.2	0	0.3
82.0	18.0	0	0.14
80.2	18.0	1.8	0.3
74.9	18.0	7.1	0.6

Table 25 Effects of ethylene on respiration rate of selected crops (source: adapted from Solomos and Biale 1975)

Crop	Respiration rate ($\mu\text{L O}_2 \text{ g}^{-1} \text{ h}^{-1}$)	
	Control	Ethylene
Apple	6	16
Avocado	35	150
Beet	11	22
Carrot	12	20
Cherimoya	35	160
Grapefruit	11	30
Lemon	7	16
Potato	3	14
Rutabaga	9	18
Sweet potato	18	22

Ethylene removal from stores

The control of internal concentrations of ethylene in crops may be ultimately limited by the resistance of the crop to diffusion rather than its removal from the atmosphere surrounding the crop (Dover 1989). However, Stow (1989a, 1989b) showed that the ethylene concentration in the core of apples was reduced by lowering the ethylene concentration in the containers in which the fruit were stored. There are various ways in which ethylene can be removed from stores (Knee *et al.* 1985, Gorini *et al.* 1989). These involve either a chemical reaction or absorption.

Absorption

Molecular sieves and activated carbon can hold organic molecules such as ethylene. When fresh air

is passed through these substances, the molecules are released. This means that they can be used in a two-stage system where the store air is being passed through the substance to absorb the ethylene while the other stage is being cleared by the passage of fresh air. After an appropriate period, the two stages are reversed. Hydrated aluminium silicate can also be used to absorb ethylene. This has a complex lattice structure forming a honeycomb network which can be lined with anions that will loosely hold any cations with which they come into contact. A natural zeolite called clinoptilolite is used. This has the following structure:



Activated charcoal, which is also called activated carbon, is used for absorbing CO₂ from stores, but it will also absorb ethylene. Baumann (1989) described a simple scrubber system that could be used in stores to remove both gases using activated charcoal. A chart was also presented which showed the amount of activated charcoal required in relation to the carbon dioxide levels required and ethylene output of the fruit in the store.

Reaction

Ethylene can be oxidised at room temperatures when it comes into contact with potassium permanganate. Proprietary products are available which can be placed inside the crop store or even inside the actual package containing the crop. The oxidizing reaction is not reversible and the granules change colour from purple to brown to indicate that they need replacing. In trials with the proprietary ethylene absorbent (Purafil) in apple stores, Blanpied *et al.* (1981) found variable efficiency in ethylene removal (Table 26). The rate of removal of ethylene with another proprietary ethylene absorbent called Ethisorb was shown to be affected by the absorption system used and the concentration of the ethylene within the store (Table 27).

Stow (1989b) showed an interaction between ethylene levels in apple stores and the concentration of O₂. He also showed that an ethylene absorbent (1 kg of vermiculite soaked with 2 L of a saturated solution of potassium permanganate) reduced the ethylene concentration in the store at all O₂ levels studied (Figure 52).

Table 26 Ethylene removal efficiency by chemisorption with 'Purafil ES' in a controlled atmosphere store containing 200 tonnes of apples (source: adapted from Blanpied *et al.* 1989)

Days in storage	Ethylene removal efficiency ^a	Ethylene concentration in store (ppm)
1	0.73	2.6
2	0.46	1.1
3	0.42	1.2
7	0.38	1.7
11	0.21	3.3
16	0.07	4.4

^a475 m³ h⁻¹ through 85 kg 'Purafil' beads.**Table 27** The rate of removal of ethylene in parts per million with Ethysorb (source: adapted from Dover and Bubb, n.d.)

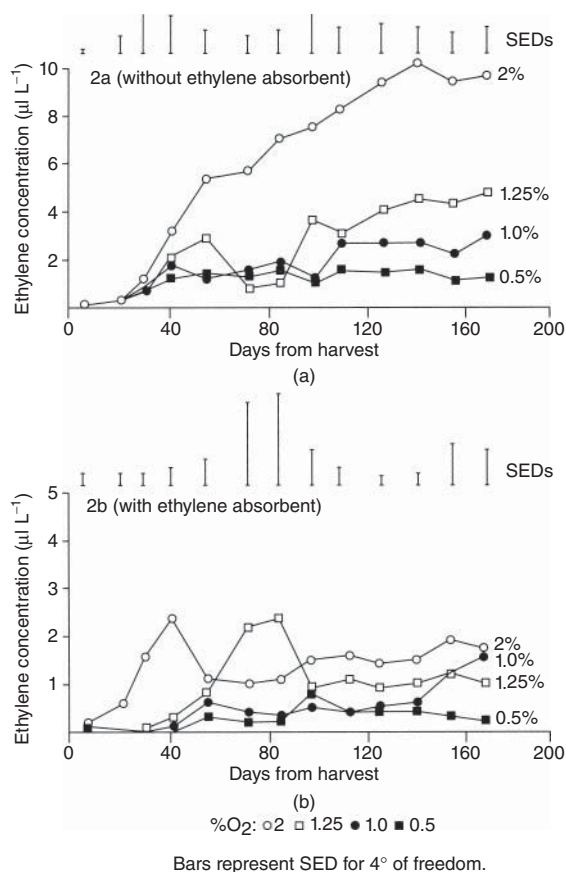
Concentration of ethylene	Rate of ethylene removal (g Ethysorb h ⁻¹)	
	Closed static system	Closed circulating system
0.01	0.023	0.028
0.10	0.230	0.280
1.00	2.30	2.800

Catalytic converters

These also remove ethylene by chemical reaction. Air from the store is passed through a device where it is heated to over 200 °C in the presence of an appropriate catalyst, usually platinum (Wojciechowski 1989). Under these conditions, the ethylene in the air is oxidised to CO₂ and water. It requires an energy input of 30–80 W m⁻³ of purified air, so it is a high energy-consuming method. However, with suitable heat exchanges, it is possible to make the method more energy efficient. One such device called the Swingtherm reduces energy consumption to 7–14 W m⁻³. Another ethylene converting device was marketed by Tubamet AG of Vaduz in Liechtenstein in 1993 and called Swingcat. Portable ethylene scrubbers are available which can be placed in a store when required (Figure 53).

Ozone scrubbers

Ozone is a powerful oxidizing agent and reacts with ethylene to produce carbon dioxide and

**Figure 52** (a,b) The effects of ethylene absorbers on the ethylene levels in controlled atmosphere stores with different O₂ levels. (Source: Stow 1989. Reproduced with permission.)

water. It can be easily generated from oxygen by ultra-violet radiation or electrical discharge. Scott *et al.* (1971) and Scott and Wills (1973) described the development of a reaction chamber that could be used in stores to remove ethylene. It consisted of a ultra-violet lamp giving out radiation at 184 and 254 nm, which produce both ozone and atomic oxygen. The stored atmosphere is passed through the reaction chamber with a fan and any ethylene it contains is rapidly oxidised. The outlet of the reaction chamber contains rusty steel wool that will react with any excess O₃ and prevent it entering the store because it could be toxic to crops or to workers in the store.



Figure 53 Portable Tubamet Swingcat ethylene scrubber in use in a wholesale packhouse in United Kingdom. See colour plate section.

Hypobaric storage

Store designs, which enable them to be kept under a vacuum, have been used for controlled atmosphere storage. The reduction in pressure reduces the partial pressure of oxygen and thus its availability to the crop in the store. The reduction in the partial pressure of the oxygen is proportional to the reduction in pressure. However, in crop stores, the humidity must be kept high and this water vapour in the store atmosphere has to be taken into account when calculating the partial pressure of oxygen in the store. To do this, the relative humidity must be measured and, from a psychrometric chart, the vapour pressure deficit can be calculated. This is then included in the following equation:

$$P_1 - \text{VPD} \times 21P_0 = \text{partial pressure of O}_2 \\ \text{in the store}$$

where:

P_0 = outside pressure at normal temperature
(760 mm Hg)

P_1 = pressure inside the store

VPD = vapour pressure deficit inside the store.

Since the crop in the hypobaric store is constantly respiring, it is essential that the store atmosphere is constantly being changed. This is achieved by a vacuum pump evacuating the air from the store. The store atmosphere is constantly being replenished from the outside. The air inlet and the air evacuation from the store are balanced in such a way as to achieve the required low pressure within the store. There are two important considerations in developing and applying this technology to crop storage. The first is that the store needs to be designed to withstand low pressures without imploding. The second is that the reduced pressure inside the store can result in rapid water loss from the crop. To overcome the first, stores have to be strongly constructed of thick steel plate with a curved interior. For the second, the air being introduced into the store must be saturated (100% r.h.), if it is less than this, serious dehydration of the crop can occur. The control of the O_2 level in the store can be very accurately and easily achieved and simply measured by measuring the pressure inside the store with a vacuum gauge. This method also has the advantage of constantly removing ethylene gas from the store, which prevents it building up to levels that could be detrimental to the crop. The effects of hypobaric storage on fruits and vegetables has been reviewed by Salunkhe and Wu (1973) and by Burg (1975), where they showed considerable extension in the storage life of a wide range of crops when it is combined with refrigeration compared to refrigeration alone. In other work, these extensions in storage life under hypobaric conditions have not been confirmed (Hughes *et al.* 1981). The hypobaric stored capsicums also had a significantly higher weight loss during storage than the air stored ones. Hypobaric storage of bananas was shown to increase their storage life. When bananas were stored at 14 °C, their storage life was 30 days at 760 mm Hg, but when the pressure was reduced to 80 or 150 mm Hg, the fruit

remained unripe for 120 days (Apelbaum *et al.* 1977). When these fruits were subsequently ripened, they were said to be of very good texture, aroma and taste.

A more recent system of hypobaric storage controls water loss from produce without humidifying the inlet air with heated water (Burg 1993). This is achieved by slowing the evacuation rate of air from the storage chamber to a level where water evaporated from the produce by respiratory heat exceeds the amount of water required to saturate the incoming

air. Using this technique with roses stored at 2 °C and $3.33 \times 10^3 \text{ N m}^2$, Burg (1993) found that flowers stored for 21 days with or without humidification at a flow rate of $80\text{--}160 \text{ cm}^3 \text{ min}^{-1}$ lost no significant vase life compared with fresh flowers.

The effectiveness of short hypobaric treatments against postharvest rots was investigated by Romanazzi *et al.* (2001), who found that it reduced fungal infections in sweet cherries, strawberries and table grapes.

8

Diseases and pests

Pests

Many pests attack fruit and vegetables in the field that can be carried through to the postharvest period. They are mainly insects, but other organisms may be involved including nematodes. In white yams, Thompson *et al.* (1973) found infection with the parasitic nematode *Pratylenchus* sp., probably *P. coffeae* (Loof.), in the field, which could cause tissue just below the skin to become necrotic. They showed that this necrosis could increase during ambient storage, because the nematodes increase in numbers. Storage at 13 °C resulted in a rapid decrease in nematode numbers in the tubers and thus prevented spoilage. When bananas were packed into export cartons in the field, there was occasional infestation of the boxed fruit by insects, mainly cockroaches and ants. Where this was a problem, it was controlled by fumigation with the broad-spectrum insecticide permethrin, usually during ripening in the importing country (Thompson and Burden 1995). Black widow spiders (*Latrodectus hesperus* Chamberlin & Ivie) have been found in grapes exported from California. Yong-Biao *et al.* (2008) exposed Thompson Seedless and Flame Seedless to different O₂ levels at different temperatures. They found complete control of the spiders after ultra low O₂ at 0.5% O₂ or lower at 1 °C and also at 2% O₂ at 15 °C both for 24 h. In 2% O₂, as temperature was increased from 1 to 15 °C, spider mortality increased from 0

to 100%. Two types of thrips attack banana fruit: the flower thrips (*Frankliniella* spp., *Thrips florum*) and red rust thrips (*Chaetanaphothrips* spp.). Flower thrips lay their eggs just below the surface of the skin of fruit that are less than 2 weeks old. The result is a small raised pimple, which can be felt on the surface particularly between the fingers. Rust thrips actually feed on the surface of the newly developing fruit usually between the fingers, especially where they are touching. Their feeding action results in light yellow patches that later turn a reddish brown colour, but at this stage, there are few, if any, rust thrips remaining. Yong-Biao (2011) investigated postharvest control of western flower thrips (*Frankliniella occidentalis*) in lettuce. They vacuum cooled seven cultivars of Iceberg lettuce and stored them at 2 °C for up to 5 days, then exposed them to ultra low O₂ (0.003% O₂) at 10 °C for 2 days. Lettuce stored for 2 days followed by 2 days ULO treatment was effective in controlling western flower thrips. Three of seven cultivars sustained injury to heart leaves by the ULO treatment but this was minimal. Lettuce that had been stored for 2, 3 or 5 days before the ULO treatment tolerated the ULO treatment with no significant quality reduction compared with untreated controls. Magnetic resonance imaging has been used to obtain images of insect damage in pears (Chen *et al.* 1989).

The most important insects that attack fruit are the fruit flies as their presence not only affects the palatability of the fruit but can affect their international

marketability. These are dealt with under different fruit and vegetable sections of this book. Insect infestation has resulted in extensive legislation from many countries to control importing of fruit containing fruit flies. Fruit flies of major concern particularly in fruit exported to countries such as Japan, USA and Australia are (Vijayasegaran 1993):

- *Anastrepha* – South America, Central America and the West Indies.
- *Ceratitis* – Africa, but has spread throughout the world except Asia.
- *Rhagoletis* – South America, Central America, North America and Europe.
- *Dacus* – mostly Africa.
- *Bactocera* – Asia, Australia and South Pacific.

Diseases

The genesis of postharvest diseases is usually in the field and can be influenced by the environment in which the crop is grown. For example, high calcium levels have been associated with reduction in postharvest disease levels, and a reduction in the nitrogen: calcium ratio has been strongly correlated with increased resistance of apple fruit to postharvest disease (Sugar *et al.* 1992). Other preharvest variables, including fruit position on the plant, growing season and water deficit, have marked effects on the postharvest characteristics and susceptibilities of fruit and vegetables (Sugar *et al.* 1992).

Postharvest diseases of fruit and vegetables are caused by infections with fungi and bacteria. Virus infections can cause diseases, which manifest themselves postharvest, but these are rare. Fungi and bacteria can exist as either parasites or saprophytes. The former feed from living matter and the latter from dead organic matter. Parasites can be obligate or facultative. Obligate parasites can only survive on living hosts, generally only attack a limited range of hosts and are very difficult or impossible to grow on artificial culture media. Facultative parasites can adapt to live on dead organic matter, often have a wide host range and can easily be cultured on artificial media. Most fungi require an acid (pH 2.5–6) environment in which to grow and develop, whereas bacteria thrive best in neutral conditions and only a few species can grow at levels below pH 4.5. Bacteria therefore do not

usually infect fruit, which are acidic. The classification of fungi are in constant review, but generally they may be unicellular or multicellular in the case of yeasts, but most fungi are made up of hyphae that are multicellular filamentous thread-like structures, which can form a dense fluffy mass, called mycelium. Many of the fungi that cause postharvest disease belong to the phylum Ascomycota and the associated fungi Anamorphici. In Ascomycota, the asexual stage of fungus, called the anamorph, is usually more frequently found in postharvest diseases than the sexual stage called the teleomorph. More comprehensive references are Snowdon (1990), Coates *et al.* (1995), Agrios (1997) and Waller (2001).

There are two basic types of diseases in plants. Non-parasitic diseases that are also called physiological disorders where there is no other organism involved and are caused by internal physiology, climatic conditions or soil conditions. The second are diseases associated with infection by organisms. These can be divided into saprophytic diseases. Parasitic diseases are also called pathogenic disease and affect the host plant by absorbing food from the host cells thus weakening the plant, secreting toxins, enzymes and growth substances, which can damage or kill the plant cells or by blocking the translocation of food and water. Some pathogenic microorganisms are fungi, bacteria, nematodes, mycoplasmas, protozoa, viruses, viroids and prions. Infection results in symptoms, which can be used for diagnosis. Sometimes, different organisms can cause the same symptoms, and sometimes, the same organism may give different symptoms depending on the crop, environment, time in the growth cycle and site of infection. Symptoms can be localised affecting only the part of the plant that is infected, e.g. leaf, fruit. They can affect the whole plant where the organism infects one part of the plant and can then spread to all parts of the plant or where one part of the plant is infected, but the symptoms are shown in another part, e.g. the roots are infected and result in wilting of the leaves and stem, which are not actually infected.

In order to be certain exactly the cause of an infection, a diagnostic series of steps must be carried out. The most commonly used is called Koch's postulate where:

- Pathogen is isolated from diseased plant.
- Pathogen is cultured.

- Pathogen is inoculated into healthy plant of the same species and cultivar.
- The same disease symptoms are observed.
- Pathogen is isolated and is the same as in two above.

For infection to take place, there must be the presence of pathogen, presence of suitable host plant at an appropriate stage of crop growth and favourable weather conditions. The most common way of infection is through damaged tissue but many organisms can penetrate through living tissue.

Barriers to infection

Plants have natural defences to infection. Physical barriers include the cuticle and the periderm, both of which may also contain chemical defence mechanisms. The cuticle is a good barrier against bacteria and especially viruses. Many fungal pathogens exude enzymes, which attack the cuticle and epidermis. Stomata, lenticels and hydrothodes are natural breaks on plant surfaces where infection can occur. Chemical barriers may exist on or in the plant or may be produced as a result of infection. They are often phenols called phytoalexins. In some cases, toxins are always present, e.g. in the scales of coloured onion bulbs and terpenes, resins and latex in some plant tissue. Plant cells may also be able to detoxify chemicals given out by the fungi or bacteria.

Phytoalexins

These are toxic substances stimulated to be produced in substantial quantities in plants as a result of infection with pathogenic microorganisms, mechanical injury or chemical injury to the plant. Phytoalexins are produced by healthy cells adjacent to damaged or necrotic cells in response to chemicals produced by damaged cells. Most are toxic to and inhibit the growth of fungi and many are toxic to bacteria, nematodes and other organisms. Pisatin is a phytoalexin in pea and is toxic to humans. Pisatin has been found that the pods of peas which had been stored in an atmosphere containing ethylene. Peas stored with levels of 0.2–20 ppm ethylene produced pisatin levels of about three times those of pods stored where ethylene was eliminated. Production of phytoalexins is stimulated in the host by elicitors given out by fungi.

These elicitors are generally high molecular weight substances in the fungal cell walls.

Physiological barriers

Some plants cells die as a response to infection, which isolates the infection, especially in response to infection by obligate parasites. This is because it forms an area of dead material around the fungus. It is called hypersensitivity.

Morphological barriers

The morphology of the plant can affect infection, e.g. in the fungus *Claviceps purpurea* that causes Ergot in cereals. In Rye, the spores settle on the open flower and germinate, such as pollen, on the stigma and infect the flower that way. Barley is self-pollinated and modern cultivars keep their flowers closed almost all the time so they are not infected.

Epidemiology

Epidemiology is the study of factors affecting the outbreak and spread of infectious diseases. An epidemic is where a pathogen spreads to and infects many individuals over a large area in a relatively short time. Epidemics develop as a result of susceptible host plants, virulent pathogen, a favourable environment over a prolonged period and human activity, e.g. monocropping. Epidemics can be controlled to some degree by legislation, breeding disease resistant plants, environmental control, chemical fungicides, biological control and cultural control.

Legislation

There is a strong aversion in many consumers to treatment of fruit and vegetables with chemical pesticides. This has resulted in increasing legislation on their use, especially after harvest. Chemical pesticide residues in fruit and vegetables are restricted and controlled by legislation. There is a United Nations body set up to provide a scientific basis for legislation called the World Health Organization (WHO) Expert Group on Pesticide Residues with the Food and Agriculture Organization (FAO) Panel of Experts on Pesticide Residues (JMPR). In Europe, the DG VI (Agriculture)

of the European Commission has the responsibility of harmonising chemical pesticide residues in food. With the introduction of Single European Market on 1 January 1993, a first list of 55 chemicals was produced that could be applied to foods. The list is constantly being updated and it contains the maximum residue levels (MRLs) for different chemicals on different crops. It provides directives for MRL, and these are communicated in directives issued in the Official Journal of the European Communities. Where no MRL exists for a certain crop and chemical, it is subject to a default level (LOD). European Union legislation is effectively removing most postharvest fungicides and insecticides from use on fruit and vegetables. This means that for a wide range of tropical crops, there are only a few permitted compounds and for some crops, none. For producers in developing countries, it is important to try every possible means of non-chemical protection to avoid problems on entry to the export markets.

COLEACP in Paris were given the task of developing an action programme to the European Commission. This has three main purposes:

- To set up a communication programme to raise awareness of the European Union harmonisation programme for pesticide regulations and to provide accurate, regularly updated and easily accessible information in a user-friendly format on MRL for tropical and minor crops produced in Asia, Caribbean and Pacific (ACP) countries and a database.
- Where MRL have been set by default at LOD, to search for available data on essential crop/chemical combinations in order to submit applications for the setting of practical MRL for GAP use in these crops. Where data are missing or inadequate, trials will be set up to establish the missing data.
- To set up mechanisms (and work with other organisations where possible) to build the capability of ACP exporters and exporter associations to develop sustainable systems of crop production, minimising pesticide use through integrated crop management and integrated pest management to comply with EU (and the USA) regulations, also to protect the health of farm workers and preserve the environment.

Control of pests and diseases can be greatly helped by appropriate legislation. Legislation can be used

to control and prevent plant material coming into a country that might be infected with pests or diseases. In other cases, material is heat treated or fumigated, but this are not permitted in many countries because of residues that may be harmful to consumers. An example of legislation being used in disease control is brown rot disease of potato, caused by the bacterium *Pseudomonas solanacearum*. It was first recorded in southern Europe in 1940 and was observed in Sweden in 1972 and in England in 1992. The largest outbreak occurred in the Netherlands in 1995, mainly through heavily infected seed tubers. To avoid introduction of this dangerous quarantine disease into other countries, the European Commission implemented the phytosanitary regulations on *P. solanacearum* in November 1995. Control measures governed by national and European Union plant health legislation rely on accurate detection and reporting of brown rot outbreaks and distribution of the pathogen, prevention of importation of potatoes from known infected areas and restrictions on use of infested land and irrigation water for potato production.

Other strategies for legislative control of plant diseases include:

- Responsibility for prevention and control is for the country where the disease occurs.
- Countries where the disease occurs should report outbreaks as soon as possible.
- Early and sure detection and diagnosis of the pathogen is essential.
- Adequate prevention and control measures should be taken after an outbreak.
- Production of healthy planting material (e.g. seed tubers) should be guaranteed and surveys and (laboratory) checks for (latent) infections performed.
- Education of scientific personnel, farmers, traders, extension service and the public is essential.

Mode of infection

Devising the correct method of control of a particular disease on a particular fruit or vegetable must take into account the identification of the organism involved and knowledge of the ecology and pathogenicity of the organism. Infection can occur before, during or after harvest, and development of

disease may be intimately associated with the physiological status of the fruit or vegetable (Coates *et al.* 1995).

Preharvest fungal infections

Conidia of *Botrytis cinerea* on the surface of necrotic strawberry flower parts germinate in the presence of moisture. The fungus colonises the necrotic tissue and then remains quiescent in the base of the floral receptacle. Several months later, when fruits are harvested, infections develop as a stem end rot in ripe fruit. Mango stem end rot caused by *Dothiorella dominicana* is one example of a postharvest disease arising from endophytic colonisation of fruit pedicel tissue. In this case, the fungus colonises the pedicel and stem end tissue of unripe fruit, where it remains quiescent until fruit ripening commences. Stem end rots of citrus caused by *Lasiodiplodia theobromae* and *Phomopsis citri* result from quiescent infections in the stem button of fruit. These infections can be initiated at any stage of fruit development and remain quiescent until the button begins to separate from the fruit during abscission. Examples of postharvest diseases that can arise from late season infections include brown rot of peach (caused by *Monilinia*), yeasty rot of tomato (caused by *Geotrichum*) and sclerotium rot of various vegetables (caused by *Sclerotium rolfsii*). Some pathogens infect through natural openings such as stomata, hydrothodes and lenticels (Coates *et al.* 1995).

Resistance to infection

Phytoalexins are only produced in response to pathogen invasion, although in some cases, they can be elicited by certain chemical and physical treatments. For example, non-ionising ultraviolet-C radiation is known to induce production of phytoalexins in various crops. UV treatment of carrot slices induces production of 6-methoxymellen, which is inhibitory to *Botrytis cinerea* and *Sclerotinia sclerotiorum* (Coates *et al.* 1995).

Natural antifungal compounds present in fruit tissue may be involved in regulating the quiescence of *Colletotrichum* infections. In avocados, antifungal dienes are present in the peel of unripe fruit at concentrations inhibitory to *Colletotrichum gloeosporioides*, the avocado anthracnose pathogen.

During ripening, levels of these dienes decline to sub-fungitoxic levels coincidentally with the development of anthracnose symptoms on fruit. Preharvest fungal infections of mangoes by *Glomerella cingulata*, the conidial stage *Colletotrichum gloeosporioides*, cause anthracnose disease. The spores of this organism may infect fruit, germinate and form appressoria that remain quiescent on the skin of the fruit until the fruit begins to ripen. The fungus then invades the cells of the fruit by hyphae growing from the appressorium resulting in the anthracnose disease. Fruit, especially those that are to be exported, are harvested at a stage of maturity where the fungus has not penetrated the fruit but is firmly fixed to its surface at the resistant appressorial stage. Therefore, fruits, which look perfectly healthy at harvest, may develop the disease symptoms postharvest. A similar effect was reported by Coates *et al.* (1993a), where spores of *Glomerella cingulata* have been shown to germinate on developing avocado fruit, form an appressoria and a short infection peg that penetrates about 1.5 µm into the skin. The fungus then remains quiescent until harvest, when antifungal dienes in the skin of avocado fruit break down due to degradation by lipoxygenase activity. The fungus then resumes growth and invades the avocado fruit to cause postharvest rots (Prusky *et al.* 1983, 1995). They also reported that it has been shown that breakdown of the dienes was delayed by controlled atmosphere storage, hypobaric storage and treatment with antioxidants.

Environment

A wide range of preharvest factors influence the development of postharvest disease. These include the weather (rainfall, temperature, etc.), production locality, choice of cultivar, cultural practices (pesticide application, fertilisation, irrigation, planting density, pruning, mulching, fruit bagging, etc.) and planting material. These factors may have a direct influence on the development of disease by reducing inoculum sources or by discouraging infection. Alternatively, they may affect the physiology of the produce in a way that impacts disease development after harvest. For example, the application of certain nutrients may improve the 'strength' of the fruit skin so that it is less susceptible to injury after harvest and therefore less prone to invasion by wound pathogens

(Coates *et al.* 1995). In the field, planting crops in an environment that is less suitable to the microorganism can be used. Examples include growing mangoes where there is a strong prevailing wind can eliminate disease and good ventilation control in greenhouses can reduce disease.

Hygiene

In the case of postharvest diseases that arise from preharvest infections, practices that make the crop environment less favourable to pathogens will help reduce the amount of infection that occurs during the growing season. For example, in tree crops, pruning and skirting can increase ventilation within the tree canopy, making conditions less favourable for fungi and bacteria. Removal of dead branches and leaves entangled in the tree canopy is also an important way to minimise inoculum build-up. In many diseases, overhead irrigation can encourage pathogen spread and infection; trickle or micro-sprinkler irrigation systems may be more appropriate. As many pathogens are soil-borne, minimising contact of leaves and fruit with the soil is desirable. Inoculum for infections occurring after harvest commonly originates from the packing shed and storage environments. Water used for washing or cooling produce can become contaminated with pathogen propagules if not changed on a regular basis and if a disinfectant such as chlorine is not incorporated. Water temperature can also be an important factor in the transfer of inoculum in some situations. For example, tomatoes harvested during hot weather may have a higher temperature than the water used to wash them. In this scenario, inoculum present in the washing water can be taken in by the fruit tissue, causing higher levels of diseases such as bacterial soft rot. Rejected produce, which has not been discarded from the packing shed or storage environment, provides an ideal substrate for postharvest pathogens. 544 Packing and grading equipment, particularly brushes and rollers, which is not cleaned and disinfected on a regular basis, can also be a major source of inoculum. Containers used for storing and transporting fruit can harbour pathogen propagules, particularly if recycled a number of times without proper cleaning (Coates *et al.* 1995).

Harvest and handling fungal infections

In some diseases, infection occurs during and after harvest through the wound created by severing the fruit from the plant as in banana crown rot. Many common postharvest pathogens are unable to directly penetrate the host cuticle and infection can occur through mechanical injury during harvesting and handling as well as insect injuries.

Infection of lychee fruit by yeasts commonly occurs through insect injuries that are difficult to see at harvest. Some chemical treatments used after harvest, such as fumigants used in insect disinfestation and disinfectants such as chlorine, may also injure produce if applied incorrectly. Various types of physiological injury such as chilling and heat injury can predispose produce to infection by postharvest pathogens. For example, the incidence of alternaria rot in pawpaw, apple and various vegetable crops is increased by exposure to excessive cold (Coates *et al.* 1995).

Non-chemical methods of disease control

Breeding

Within a natural population of plants of the same species, there will be differences in the susceptibility to disease, which can be exploited in breeding and selection. Microorganisms can also mutate or, from natural variation, can infect resistant plants. Genetic modification (GM) has great potential for disease control and can be used by inserting a gene into a crop that gives it resistance to a particular disease. However, there is resistance to the method from the public of many countries. In September 2003, over 50 countries signed the Cartagena Protocol on biodiversity so that any country can refuse to import any genetic modified organism (USA refused to sign the Protocol)

Ionising radiation

Ionising radiation is another physical treatment that can be used after harvest to reduce disease in some commodities. Like heat, commodities must be able to tolerate the doses of ionising radiation required to achieve disease control. Some commodities are surprisingly tolerant. For example, strawberries can

Table 28 Effects of controlled atmosphere storage conditions on the decay levels of tomatoes harvested at the green mature stage (source: adapted from Parsons *et al.* 1974)

Storage atmosphere	After removal from 6 weeks at 13 °C (%)	Plus 1 week at 15–21 °C (%)	Plus 2 weeks at 15–21 °C (%)
Air (control)	65.6	93.3	98.6
0% CO ₂ + 3% O ₂	2.2	4.4	16.7
3% CO ₂ + 3% O ₂	3.3	5.6	12.2
5% CO ₂ + 3% O ₂	5.0	9.4	13.9

tolerate the doses of radiation required to effectively control grey mould. In other commodities, however, abnormal ripening, tissue softening and off-flavours can result from applying ionising radiation at doses lethal to the target pathogens. Poor consumer acceptability of food irradiation coupled with high treatment costs pose additional limitations to the widespread use of this technology at the present time (Coates *et al.* 1995).

Considerable interest exists in controlling postharvest diseases and pests of crops without using chemical fungicides. There are several alternative strategies, some of these are dealt with in the following.

Hot water treatment

Hot water dipping of mangoes to control anthracnose can result in increased levels of stem end rot (caused by *Dothiorella* spp.) (Coates *et al.* 1995).

Storage

The natural resistance of fruit and vegetables to disease declines with storage duration (Coates *et al.* 1995).

Ethylene

Exposure of parsnips to low levels of ethylene in cold storage caused bitterness that was probably due to accumulation of the phytoalexin xanthotoxin (8-methoxypsoralen) (Johnson *et al.* 1973).

Carbon dioxide

In a review of the fungistatic effects of high CO₂, Kader (1997) indicated that levels of 15–20% could retard decay incidence on cherry, blackberry, blueberry, raspberry, strawberry, fig and grape. In

celery stored at 8 °C, disease suppression was greatest in atmospheres of 7.5–30% CO₂ with 1.5% O₂, but there was only a slight reduction in 4–16% CO₂ with 1.5% O₂ or in 1.5–6% O₂ alone (Reyes 1988). Pretreatment of Italia grapes with 20% CO₂ for 48 h before storage reduced decay during subsequent storage at 0 °C and 90–95% r.h. for 30 days in both types of grape. It had a marked effect during the first 10 days of cold storage on organic grapes (Massignan *et al.* 1999). Summer Red nectarines tolerated air enriched with 15% CO₂ atmosphere for 16 days at 5 °C. Development of brown rot decay in fruits inoculated with *Monilinia fructicola* 24 h before storage was arrested. After 3 days' ripening in air at 20 °C, the progression of brown rot disease was rapid in all inoculated nectarines, demonstrating the fungistatic effect of CO₂ (Ahmadi *et al.* 1999). Eris and Akbudak (2001) found that peaches stored at 0 °C and 90% r.h. had lower levels of decay in 5% CO₂ and 2% O₂ than in air. Control of infections by the anthracnose and crown rot pathogen of bananas by exposure to 15% CO₂ or 1% O₂ resulted in a reduction in growth of the pathogen but not complete inhibition (Al Zaemey *et al.* 1994). Also that level of CO₂ is toxic to the fruits, so this does not appear to be an alternative to fungicides.

Oxygen

Reports on the effects of reduced O₂ levels in storage on the development of diseases of fruit and vegetables have shown mixed results, but some positive effects have been reported. Parsons *et al.* (1974) showed considerable reduction in disease levels on tomatoes in controlled atmosphere storage with most of the effect coming from the low O₂ levels with little additional effect from increased CO₂ levels (Table 28). Exposure of organically grown Ziv bananas to 2% O₂ atmosphere at 20 °C for either 48 and 72 h immediately after harvest was effective in reducing crown

rot decay after simulated transport, ethylene ripening and shelf life, but less so than 0.2% thiabendazole fungicide treatment (Pesis *et al.* 2001).

Curing

Many root crops have a cork layer over the surface that is called a periderm. This serves as a protection against microorganism infections and excessive water loss. This layer can be broken or damaged during harvesting and handling operations, so curing is essentially a wound healing operation to replace the damaged periderm. Sealing citrus fruits in plastic film bags and then exposing them to 34–36 °C for 3 days resulted in the inhibition of *Penicillium digitatum* infection and reduced decay and blemishes through lignification and an increase in antifungal chemicals in the peel of the fruit without deleterious effects on the fruit (Ben Yehoshua *et al.* 1989a, 1989b). In potatoes, there are some indications that the fatty acids may also act as phytoalexins and the peroxides and epoxides may have toxic effects on infectious agents (Galliard 1975).

Biological control

Microbial antagonists are applied either before or after harvest, but postharvest applications are more effective than preharvest applications. Mixed cultures of the microbial antagonists appear to provide better control of postharvest diseases over individual cultures or strains. Similarly, the efficacy of the microbial antagonist(s) can be enhanced if they are used with low doses of fungicides, salt additives and physical treatments such as hot water dips, irradiation with ultraviolet light, etc. (Sharma *et al.* 2009).

In most reported cases, pathogen inhibition is greater when the antagonist is applied before infection taking place. For this reason, control of quiescent field infections (e.g. *Colletotrichum gloeosporioides*) using postharvest applications of antagonists is often more difficult to achieve than control of infections occurring after harvest (e.g. *Penicillium* spp.). Unless an antagonist has eradicator activity or has some effect on host defence responses, field applications are often necessary to achieve control of quiescent infections. In South Africa, both field and postharvest applications of *Bacillus subtilis* and *B. licheniformis* suppressed anthracnose (caused by

Colletotrichum gloeosporioides) and stem end rot (caused by *Dothiorella* spp. and other fungi) development in avocado. A number of modes of action are involved in these pathogen-antagonist interactions, including site exclusion, nutrient and space competition and antibiotic production. In Australia however, only field applications of a non-antibiotic producing strain of *Bacillus* sp. have shown potential for the control of anthracnose in avocado. There are a number of reports in the literature concerning the biological control of wound pathogens in various fruit and vegetables. To be effective against wound pathogens, an antagonist must be able to successfully colonise wound sites to the exclusion of the pathogen. Microbial antagonists are being used including *Debaryomyces hansenii* Lodder & Krejer-van Rij, *Cryptococcus laurentii* Kufferath & Skinner, *Bacillus subtilis* (Ehrenberg) Cohn, and *Trichoderma harzianum* Rifai. Biocontrol products including Aspire, BioSave and Shemer have also been developed and registered (Sharma *et al.* 2009). Antagonists that act against postharvest pathogens by competitive inhibition at wound sites include the yeasts *Pichia guilliermondii*, *Cryptococcus laurentii* and *Candida* spp. (Coates *et al.* 1995). The bacteria *Streptomyces* and *Pseudomonas* can attack *Pythium* and other fungi.

Microbial antagonists

Microbial antagonists are used to control several postharvest diseases. Although the mechanism(s) by which microbial antagonists suppress the postharvest diseases is still unknown, competition for nutrients and space is most widely accepted mechanism of their action. In addition, production of antibiotics, direct parasitism and possibly induced resistance in the harvested commodity are other modes of their actions by which they suppress the activity of postharvest pathogens in fruit and vegetables (Sharma *et al.* 2009). Microbial antagonists are applied either before or after harvest, but postharvest applications are more effective than preharvest applications. Mixed cultures of the microbial antagonists appear to provide better control of postharvest diseases over individual cultures or strains. Similarly, the efficacy of the microbial antagonist(s) can be enhanced if they are used with low doses of fungicides, salt additives and

physical treatments such as hot water dips, irradiation with ultraviolet light, etc. At the international level, different microbial antagonists such as *Debaryomyces hansenii* Lodder & Krejer-van Rij, *Cryptococcus laurentii* Kufferath & Skinner, *Bacillus subtilis* (Ehrenberg) Cohn and *Trichoderma harzianum* Rifai are being used. Biocontrol products such as Aspire, BioSave, Shemer, etc., have also been developed and registered.

Yeasts

It has been known for many years that some microorganisms found on the surfaces of growing plants can attack potential fungal pathogens. Some yeasts have been shown to be effective. Aspire is a commercial formulation of the yeast *Candida oleophila* registered for postharvest application to citrus for the control of green mould (*Penicillium digitatum*). Its mode of action appears to be that it competes with the pathogen for nutrients released by injuries. The yeast *C. guilliermondii* was shown to be antagonistic towards *Penicillium* spp. (McGuire 1993) and could be successfully incorporated into the commercial citrus waxes FMC 705, FMC 214 and Nature Seal, where it was shown to survive for 2 months at 12 °C. In trials by Brown *et al.* (2000) with Hamlin and Valencia oranges, colonisation by *C. oleophila* of puncture-related injuries that either encompassed oil glands or individually ruptured glands was achieved within 1–2 days at 21 °C. Ruptured oil glands were colonised more effectively if treated 7 h after injury rather than immediately as peel oil was toxic to *C. oleophila* but not to *P. digitatum* spores. Colonisation of puncture injuries by the yeast was comparable after 2 days at 21 and 30 °C, but no colonisation occurred at 13 °C. Growth rates of the yeast were similar in waxed and non-waxed fruits. *C. oleophila* colonised punctures more uniformly than individually damaged oil glands, and provided more effective control of *P. digitatum* originating at punctures than at oil gland injuries. Incubating treated fruits at 30 °C for 2 days before storage at 21 °C enhanced the control of *P. digitatum*.

Arras and Arru (1999) also evaluated the fungitoxic activity of antagonist yeasts against postharvest citrus fruit diseases. Trials were first performed in the laboratory using the yeasts *Pichia guilliermondii* (strain 5A), *Candida oleophila* (strain 13L) and

Rhodotorula glutinis (strain 21A), and Aspire. *P. guilliermondii* 5A strongly inhibited *P. italicum* on artificially wounded Oroblanco (a hybrid between pummelo and grapefruit) fruits with Aspire coming second. More than 200 yeasts were selectively isolated from microbial populations on the surface of different fruits by Lima *et al.* (1998) and tested against various postharvest fruit pathogenic fungi. At 20 °C, the antagonists significantly reduced rot incidence and showed a wide range of activity on different host–pathogens combinations. Two of the yeasts grew in culture at temperatures ranging from 0 to 35 °C. In assays performed *in vitro* at 24 °C, the antagonists showed low sensitivity towards several fungicides common on fruit and vegetables. Antagonistic epiphytic yeasts were isolated from the surface of mandarin orange in Turkey and grapefruit in Israel by Kinay *et al.* (1998). Among the mandarin orange isolates, three were effective in inhibiting green mould. Among the grapefruit isolates, several yeasts showed high efficacy against green and blue mould and sour rot caused by *Geotrichum candidum*. At the wound site, the population of yeasts increased gradually and maintained a high concentration during 1 week of storage at 20 °C. Teixeira *et al.* (1999) found that preharvest application of the antagonistic yeast *Candida sake* on Golden Delicious apples was less effective against *Penicillium* rot *Penicillium expansum* than postharvest treatment. No advantages in biocontrol were observed when cold-stored apples were treated with the yeast antagonist both preharvest and postharvest.

The inclusion of a *Bacillus* species or a rose coloured yeast isolated from lemon leaves in either carnauba or polyethylene wax on citrus fruits was not effective in postharvest disease control (Visintin *et al.* 1996).

Manso and Nunes (2012) isolated yeasts from the surface of Bravo de Esmolfe apples cultivated in North Portugal and found that the most effective in controlling diseases was *Metschnikowia andauensis*, strain NCYC 3728 (PBC-2). In semi-commercial trials in cold storage, the reduction of blue mould *Penicillium expansum* was 90%. Rapid colonisation of fresh apple fruit wounds was observed during the first 24 h of cold storage, followed by a significant population increase during the first 15 days of storage and then the population remained stable until the end of storage. The broad spectrum of action of *M. andauensis* PBC-2 was evaluated

with effective control being achieved against *Rhizopus stolonifer*, *Penicillium expansum* and *Botrytis cinerea*, on Rocha pears and on different apple cultivars and against *P. digitatum* and *P. italicum* on mandarins and oranges.

Other fungi

The yeast-like fungus, *Aureobasidium pullulans* (isolate LS-30), displayed antagonistic activity against *Botrytis cinerea*, *Penicillium expansum*, *Rhizopus stolonifer* and *Aspergillus niger* on Italia grapes, and *B. cinerea* and *P. expansum* on Royal Gala apples (Castoria *et al.* 2001). Yam tubers that were sprayed with a conidiospore suspension of *Trichoderma viride* in potato dextrose broth showed a large reduction in the range and number of microflora, including pathogens, on the tuber surface during 5 months storage in a traditional yam barn (Okigbo and Ikediagwu 2001).

Bacteria

Several types of bacteria that attack fungi have been isolated from plants. *Bacillus* spp. on their own or combined with a fungicide could be used to control postharvest diseases of mangoes, avocados and litchi. *B. subtilis* and *B. licheniformis* isolated from mango leaves and applied to fruit as a warm water dip controlled anthracnose levels. The effects were enhanced by the inclusion of either benomyl or prochloraz to the dip. *Bacillus* spp. isolated from leaves and fruit of avocados were more effective in controlling anthracnose and stem end rot of avocados when applied as a postharvest dip than prochloraz applied in the same way. The combination of *B. subtilis* and prochloraz was more effective than when they were applied separately. *B. stearothermophilus*, *B. megaterium* and *B. licheniformis* isolated from the phylloplane of litchi were more effective in reducing fruit browning and postharvest decay of litchi than benomyl when the treatments were applied as warm water dips. Good results have been found in the control of anthracnose in mangoes and avocados with *Bacillus subtilis*. While not giving complete control, it may have an application in reducing the levels of chemical fungicide application (Korsten *et al.* 1993a, 1993c). *In vitro* studies of *Bacillus stearothermophilus*, *B. megaterium* and *B. licheniformis* isolated from litchi trees

showed that they effectively inhibited growth in 11 postharvest pathogens of litchi fruit. Postharvest dips with these antagonists were shown to be more effective in controlling decay, postharvest infection and fruit browning than a warm water plus benomyl treatment (Korsten *et al.* 1993b).

Pseudomonas syringae strains ESC-10 and ESC-11 produce syringomycin and control green and blue moulds of citrus caused by *Penicillium digitatum* and *P. italicum*, respectively (Bull *et al.* 1998). Isolates of *Pseudomonas syringae* NSA-6 and MA-4 reduced brown rot *Monilinia fructicola* to 28 and 73%, respectively, from 98% in the inoculated control after 5 days incubation at 22 °C. Both isolates reduced rhizopus rot *Rhizopus stolonifer* to 5 and 8% from 53% in the inoculated control after 5 days incubation. Isolates MA-4 and NSA-6 suppressed brown rot from 63 to 30% and from 95 to 71–81%, respectively, after 3 and 4 days incubation at 22 °C. The use of 0.5% calcium chloride in the soak suspension significantly improved the activity of *P. syringae* but the use of 'peach wax' (Decco 282) increased brown rot incidence and negated the beneficial effect of calcium chloride (Zhou *et al.* 1999). Silimela and Korsten (2000) tested plastic caps with an added inner wool lining impregnated with copper oxychloride or the bacterial antagonist *Bacillus licheniformis* covering individual fruit. They found that they had little effect in controlling disease under field conditions when the disease pressure was low. *Pseudomonas* sp. isolates, associated with the skin of banana, inhibited germination and appressoria formation *in vitro* of conidia of *Colletotrichum musae* (de Costa and Subasinghe 1998). It also inhibited the growth of *Fusarium* spp., *Botryodiplodia* spp. and *Ceratocystis paradoxa* by 30–42%. Crown rot was significantly reduced using the antagonistic bacteria as a postharvest dip.

Bacillus thuringiensis has been used for controlling insects for many decades. Its postharvest use in controlling tuber moth (*Phthorimaea operculella*) in stored potatoes was described by Das *et al.* (1998).

Ultraviolet light

When air is passed through UV light, some of the oxygen molecules are broken down for an instant to atomic oxygen and ozone. This can have the effect of destroying pathogens when the fruit or vegetable is passed through the light. Stevens *et al.* (1997)

found that it appeared to be only partially effective in practice, and it was concluded that UV-C and yeast biological control agents could be used together as an alternative to chemical control of some storage diseases. Romanazzi *et al.* (2006) reduced grey mould incidence and severity. However, other workers have had more positive results in UV-C alone, reducing postharvest decay on strawberries (Nigro *et al.* 2000, Pombo *et al.* 2011) and mangoes (González-Aguilar *et al.* 2001) and bacterial counts on fresh-cut baby spinach leaves (Escalona *et al.* 2010), watermelon cubes (Artés-Hernández *et al.* 2010) and white mushrooms (Guan *et al.* 2012). UV-C irradiation has also been reported to have other effects. Jiang *et al.* (2010) reported that UV-C irradiation resulted in maintenance of firmness and enhanced antioxidant capacity in shiitake mushrooms. Kim *et al.* (2010) found that UV-C irradiation maintained the quality of strawberries. Kasim and Kasim (2012) found that it prevented yellowing in fresh-cut cress but increased electrolyte leakage due to tissue damage. Obande *et al.* (2012) describes a mobile UV-C unit that was conveyed between the rows of tomato plants in a commercial glasshouse and generally found that fruit treated while still on the plant softened and changed colour more slowly after harvest than those not treated.

Irradiation

Irradiation at 0.05–0.06 kGy may be used to inhibit sprouting and extend shelf life of fresh ginger (Wu and Yang 1994, Mukherjee *et al.* 1995). However, irradiation at these low levels decreased volatile content of fresh ginger, which was perceived by sensory analysis after 5 months in storage (Wu and Yang 1994). Irradiation of dried rhizomes at doses of 5–10 kGy prevented mould and bacteria growth (Dubey and Tiwari n.d.). Xu et al. (2003) suggested irradiation of modified atmosphere packs of fresh-cut iceberg lettuce with γ irradiation at 0.5–1 kGy to slow oxidation processes and to improve sensory properties. Sprout suppression of onion bulbs can also be achieved by irradiating the bulbs with doses of 20–30 Gy. This level completely prevented sprouting if applied as soon as possible after harvest (Chachin and Ogata 1971). Lu *et al.* (1987) reported that low doses of UV-irradiation induced resistance in onions to postharvest rots. The use of γ irradiation to control sprouting and increase the length of storage time

of potatoes has been proposed as an alternative to cold storage or the use of chemical sprout suppressants. The effects of different levels of γ irradiation on seven potato cultivars were investigated in relation to chlorophyll and glycoalkaloid synthesis on subsequent exposure to light after a period of storage. There were significant genotype differences between cultivars in their response to γ irradiation, with some cultivars exhibiting dramatically reduced levels of glycoalkaloid synthesis compared with others. Also, cultivars responded differently to variable irradiation levels (Dale *et al.* 1997). Irradiation of at least 35 Gy can be used to suppress sprouting in potatoes (Burton and Hannan 1957, Ranganna *et al.* 1997). Sparrow and Christensen (1954) showed that irradiated tubers did not sprout during 15 months storage at 4.4 °C. A dosage rate of 100 Gy was found to be adequate, but lower rates of about 35 Gy can be used to delay sprouting without the side effects which were observed on tubers exposed to higher doses (Burton and Hannan 1957). Dallyn and Sawyer (1959, quoted by Salunkhe *et al.* 1991) demonstrated interactions between temperature and dosage of irradiation. They also showed that a dose of 100 Gy was effective in preventing sprouting of potatoes in storage for 6 months at 10 and 21.1 °C, but 50 Gy was equally effective when the tubers were stored at 4.4 °C. Leszczynski *et al.* (1992) also showed that irradiation inhibited sprouting throughout 6 months storage at 4, 7 or 13 °C. Irradiation can affect tuber quality. Russet Burbank tubers were irradiated with 0, 50, 100 or 200 Gy of γ rays and then stored for 3 months at 10 or 15.5 °C. Irradiation decreased reducing and non-reducing sugar contents after storage. Irradiation at 200 Gy decreased reducing sugars from 1.7 to 0.9%. Irradiation at 100 Gy dosage caused the least changes (5% decrease) in non-reducing sugar content (Badshah *et al.* 1990).

The cultivars Desiree and Metal tubers were irradiated with 0, 50, 100 and 500 Gy γ rays and stored at 5 or 20–25 °C for 6 months. The control samples of Desiree showed higher respiration rates than the irradiated tubers (Alwakdi *et al.* 1991). The cultivars Janka, San and Bobr tubers were exposed to γ radiation (150 Gy) and together with untreated tubers were stored for 6 months at 4, 7 or 13 °C and 85–90% r.h. Irradiated tubers were lower in starch content, but higher in sugar content, especially sucrose. Irradiation increased susceptibility to

enzymic browning. Chip quality did not depend on irradiation but on storage temperature. The highest dry matter losses occurred in non-irradiated tubers stored at 13 °C for 6 months and the highest starch losses in irradiated tubers stored at 4 °C (Leszczynski *et al.* (1992)). Although the law may permit this, there is consumer resistance and economic factors against its use and it is rarely applied commercially.

Irradiation at doses of between 7.5 and 15 krad inhibited sprouting of *D. rotundata* during 6 months storage without inducing adverse changes in acceptability or physiological properties (Vasudevan and Jos 1992). They also reported differences in varietal responses to γ irradiation. Osunde (2008) reported that an average dose of 120 Gy and a dose rate of 114 Gy h⁻¹ were applied to the cultivar Asana and stored for 6 months in a barn or on the ground; results showed that irradiation reduced sprouting in both storage types. However, there was less rotting in the non-irradiated yams stored on the ground than the irradiated ones. Also, food products made from irradiated yams were judged to be better in quality than those made from the non-irradiated ones (Vasudevan and Jos 1992).

Irradiation of king oyster mushrooms with 1 kGy was most effective in extending storage in polystyrene trays covered with PVC film for 4 weeks at 5 ± 1 °C. Hunter L values (lightness) increased after irradiation and remained high throughout the storage period in the irradiated samples. One kilogray irradiated samples maintained an overall better texture than those not irradiated or those irradiated with 2 or 3 kGy (Akram *et al.* 2012). Fernandes *et al.* (2012) studied the effects of γ radiation at 0, 0.5 and 1 kGy on Saffron Milkcap *Lactarius deliciosus* during storage for up to 8 days at 5 °C. They found that irradiation and cold storage did not significantly affect the physical properties but there was a slight decrease in redness in those that had been irradiated.

Organic volatiles

Some organic volatile compounds produced by fruit are thought to have an effect on fungi. The inhibitory effect of (E)-2-hexenal, a volatile component of many fruits, especially after wounding, was studied for its potential for controlling mould development on fruits during storage by Archbold *et al.* (2000). One hundred millilitre of the compound was placed in 1-L

low density film wrapped clamshell containers with 150 g of either the blackberry cultivar Chester Thornless or the grape cultivar Flame Seedless and stored at 2 °C for 7 days. Following removal of the over-wrapped film and chemical from the containers and transfer to 20 °C, mould development was reduced at 20 °C following 14 days of exposure to (E)-2-hexenal in 2 °C storage.

Essential oils

Essential oils may provide alternatives and supplements to conventional antimicrobial additives in foods. Elgayyar *et al.* (2001) evaluated essential oils extracted from anise, angelica, basil, carrot, celery, cardamom, coriander, dill weed, fennel, oregano, parsley and rosemary against *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli* O:157:H7, *Yersinia enterocolitica*, *Pseudomonas aeruginosa*, *Lactobacillus plantarum*, *Aspergillus niger*, *Geotrichum* and *Rhodotorula*. Oregano essential oil showed the greatest inhibition. Coriander and basil were also highly inhibitory to *E. coli* O:157:H7 and to the other bacteria and fungi tested. Anise oil had little inhibitory effect on bacteria but it was highly inhibitory to the fungi. There was no inhibition of either fungi or bacteria with carrot oil.

Arras and Usai (2001) in *in vitro* studies found that *Thymus capitatus* essential oil at 250 μ L L⁻¹ had fungitoxic activity against *Penicillium digitatum*, *P. italicum*, *Botrytis cinerea* and *Alternaria citri*. The fungitoxic activity of *T. capitatus* essential oils at 75, 150 and 250 ppm on healthy orange fruits, inoculated with *P. digitatum* by spraying and placed in 10-L desiccators, was weak at atmospheric pressure (3–10% inhibition at all three concentrations). In vacuum conditions (0.5 bar), conidial mortality on the exocarp was high at 90–97% at all three concentrations. These data proved not to be statistically different from treatments with thiabendazole at 2000 ppm.

Nitrous oxide

Qadir and Hashinaga (2001) showed that fumigation with a mixture of 80% N₂O with 20% O₂ delayed the appearance of disease and reduced the lesion growth rate on fruit. This response to N₂O was dose- and time-dependent. This suppression of decay by N₂O treatment was thought to be a direct inhibitory effect

on fungal growth rate and/or increased resistance of host tissue. The fruit and diseases tested included Fuji apples, inoculated with *Alternaria alternata* and *Penicillium expansum*, Toyonoka strawberries with *Botrytis cinerea*, *Fusarium oxysporum* f. sp. *fragariae* and *Rhizopus stolonifer*, Satsuma mandarin with *Geotrichum candidum*, Momotaro tomato with *F. oxysporum* f. sp. *lycopersici*, Fuyu persimmon with *Colletotrichum acutatum* and seedling guava with *R. stolonifer*.

Sodium carbonate

Immersion of lemons in a 3% solution of sodium carbonate plus hot water treatment at 52 °C was as effective as imazalil treatment against *Penicillium digitatum* (Lanza *et al.* 1998).

Jasmonates

Methyl jasmonate is a plant growth regulator and there is evidence that jasmonates can also affect microorganisms. Droby *et al.* (1999) showed that postharvest application of jasmonic acid and methyl jasmonate reduced decay caused by the green mould *Penicillium digitatum* after either natural or artificial inoculation of Marsh Seedless grapefruit. The most effective concentration of jasmonates for reducing decay in cold-stored fruits or after artificial inoculation of wounded fruit at 24 °C was 10.5 mol L⁻¹. They suggest that the effect was indirect by enhancing the natural resistance of the fruits to *P. digitatum* at high and low temperatures. Exposure of cultures of *Aspergillus flavus* to methyl jasmonate vapour by Goodrich-Tanrikulu *et al.* (1995) inhibited aflatoxin production. The amount of aflatoxin produced depended on the timing of the exposure. Yao and Tian (2005) found that preharvest sprays of sweet cherry fruit with 0.2-mM methyl jasmonate reduced lesion diameter of *Monilinia fructicola*, but had little inhibitory effect on mycelial growth and spore germination.

There has been considerable research on the physiological properties of jasmonates, for example in mangoes where Gonzalez-Aguilar *et al.* (2000a, 2000b) showed that treatment with methyl jasmonate may prevent chilling injury symptoms without altering the ripening process. Droby *et al.* (1999) found that jasmonic acid and methyl jasmonate effectively

reduced chilling injury in Marsh Seedless grapefruit after cold storage. Meir *et al.* (1996) suggested that methyl jasmonate might mediate the plant's natural response to chilling stress, and by its application might provide a simple means to reduce chilling injury in chilling-susceptible commodities such as avocado, grapefruit and capsicums.

Cai *et al.* (2011) found that methyl jasmonate enhanced activities of ascorbate peroxidase, glutathione peroxidase and glutathione-S-transferase and they suggested that methyl jasmonate can regulate the ascorbate and glutathione metabolism and has important roles in alleviating oxidative damage and enhancing chilling tolerance in loquat fruit.

The combination of exposure to hot air at 38 °C for 12 h and then 1 µmol L⁻¹ methyl jasmonate at 20 °C for 24 h vapour treatment reduced chilling injury and maintained fruit quality during storage at 0 °C for up to 5 weeks plus 3 days at 20 °C for shelf life. The effects of the treatment compared to those not treated included: higher percent of extractable juice, TSS was 25.3% higher and total acid was 62.5% higher, vitamin C and total phenolic contents and higher activities of PAL, SOD and PG, and lower activities of PPO and POD (Jin *et al.* 2009).

Acibenzolar

Acibenzolar (S-methyl benzo [1,2,3]thiadiazole-7-carbothioate) is a chemical activator of induced systemic acquired resistance. When it was applied to strawberry plants at 0.25–2.0 mg a.i. ml⁻¹ to harvested strawberry fruit by Terry and Joyce (2000), it delayed the development of grey mould by about 2 days during storage at 5 °C.

Acidification

Thompson *et al.* (1992) found that in *in vitro* studies, both the germination and growth of *Colletotrichum musae* was greatly reduced at pH 3 in 15 °C. Al Zaemey *et al.* (1993) studied fruit coating and organic acids on *in vitro* control of *C. musae*, but although reductions in the growth of the fungus were observed, there was no complete control.

Coatings

Banks (1984) described a fruit coating called Tal Prolong, which consisted of sucrose esters of fatty

acids and carboxy methylcellulose and showed some reduction in levels of disease on apples coated with Tal Prolong compared to none treated fruit. Banana crowns coated with Semperfresh, which is similar to Tal Prolong and is also made up of sucrose esters of fatty acids and carboxy methylcellulose, showed delayed development of crown rot caused by infection with *Colletotrichum musae*. This effect could be enhanced by the inclusion of organic acids to the coating material (Al Zaemey *et al.* 1993).

Fungicidal chemicals

A large number of chemicals are applied to crops to control fungi that cause diseases. Laws to protect the consumer strictly govern their use, and these laws may vary between countries although most countries conform to the Food and Agriculture Organization of the United Nations and the World Health Organisation regulations. Some chemicals are permitted to be applied to crops only before harvest and the interval of time that must take place between application and harvesting is usually specified. Others are also allowed to be applied postharvest, usually with strict regulations on the maximum permitted residue, the MRL that can remain in the crop. Residue levels of chemical fungicides in a crop are related to the concentration of the chemical used, but also to the time of the crop in storage and the formulation of the fungicide (Table 29).

Fungi are constantly changing, and where a particular chemical fungicide is constantly used, strains of the fungus may develop which are tolerant to that chemical. This commonly occurs with the benzimidazole group of fungicides. Benomyl, which

is a member of the benzimidazole group, was used to control postharvest diseases of yams (Thompson *et al.* 1977). However, during commercial application, a rot caused by infection with *Penicillium sclerotigenum* was frequently observed on the tubers. In *in vitro* tests, this organism was found to be tolerant to benomyl (Figure 54). This tolerance was confirmed in *in vitro* tests, but the organism was highly susceptible to the fungicide imazalil, which gave good control of the disease (Table 30).

The application of some chemicals can actually lead to an increase in the level of disease. An example

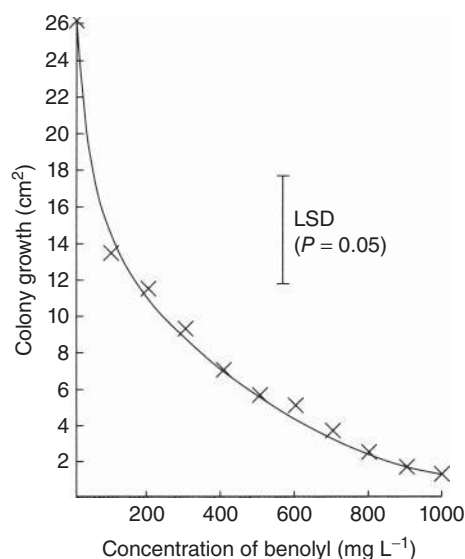


Figure 54 Colony size of *Penicillium sclerotigenum* on potato dextrose agar containing different concentrations of benomyl fungicide after 14 days at 25 °C. (Source: Plumbley *et al.* 1985. Reproduced with permission of John Wiley & Sons Ltd.)

Table 29 Residue levels in microlitres per litre after storage at 21 °C on the skin and in the pulp of citrus fruits of benomyl applied at 0.5 g L⁻¹ in water or in oil emulsion (source: adapted from Papadopoulou Mourkidou 1991)

Storage period	Water	Oil
<i>Residue in the skin</i>		
1 day	0.17	0.83
8 days	0.14	0.52
21 days	0.01	0.13
<i>Residue in the pulp</i>		
1 day	Not detectable	0.01
8 days	0.01	0.03
21 days	0.05	0.14

Table 30 Effects of benomyl and imazalil on the growth (in cm²) of a benomyl-tolerant strain of *Penicillium sclerotigenum* on yam tubers (*Dioscorea cayenensis*) during storage at 20 °C (source: adapted from Plumbley *et al.* 1984)

Treatment	Storage time in days			
	7	14	21	28
Control	1.1	2.2	3.2	3.7
Benomyl (500 ppm)	0.8	1.9	2.1	3.5
Benomyl (1000 ppm)	0.6	1.3	2.4	3.0
Imazalil (500 ppm)	0.0	0.0	0.0	0.0
LSD ($p = 0.05$)	0.56			

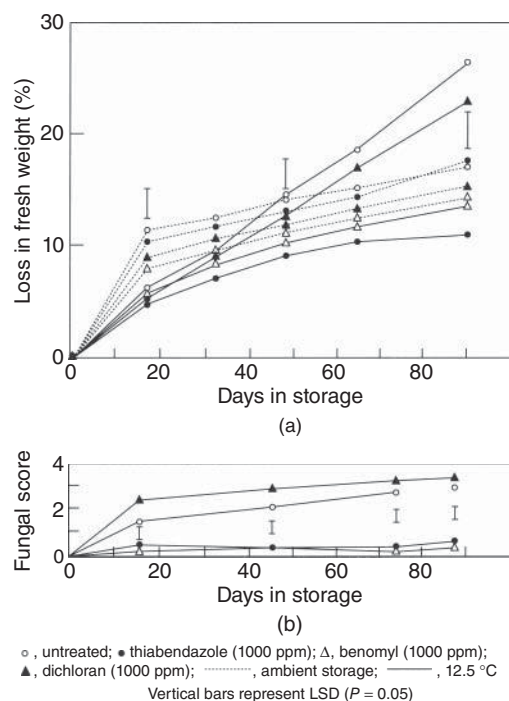


Figure 55 Effects of fungicide treatment on (a) weight loss and (b) the level of surface fungi on stored yams. (Source: Thompson *et al.* 1977.)

of this is the postharvest application of dichloran to control postharvest diseases of yams (Thompson *et al.* 1977). The reason for the increase (Figure 55) was probably due to synergy between the various organisms that were infecting the tuber.

Control of bacteria by chemicals is not normally necessary and where it is practised, it usually achieved by dipping or washing the crop in a solution containing active chlorine at $75\text{--}125\text{ }\mu\text{L L}^{-1}$. Household bleach is often used as the source of chlorine. Abu Baker and Abdul-Karim (1994) showed that dipping sapota fruit in the fungicides benomyl, captan or captan not only reduced the fungal population on the fruit but also the bacterial population. Most of these chemicals are toxic to human beings; therefore, great care must be observed during handling the chemicals, especially before they are diluted, and appropriate protective clothing must be worn.

Chemical application methods include:

- Dipping or spraying the crop in a solution or suspension of the chemical, this may be in hot

water to enhance control. The crop may be passed below a shower of the diluted chemical. This is called cascade application.

- Applying the chemical as a spray but producing very fine particles and then charging them to give a fine even coat of chemical over the crop.
- Applying the chemical as a dust, usually the active chemical diluted with an inert powder such as talc.
- Volatile chemicals can be applied as a vapour that is circulated in a confined space containing the crop. Some chemicals need to be heated to aid circulation, and this process is called thermal fogging. In other cases, chemicals that have a high thermal stability can be burnt and the smoke introduced into the store.
- The chemical may be absorbed onto a pad made of suitable material such as absorbent paper. These pads are placed over cut surfaces such as the cut crown of a hand of bananas. In this case, the pad absorbs latex from the cut surface which also helps keep the pad in position.

Dipping

The crop or part of the crop is immersed in water containing an appropriate concentration of a chemical that is toxic to the fungi, which are known to cause disease on that crop. However, the chemical must be either not toxic to the crop or have acceptable levels of toxicity. The residue of the chemical remaining in the crop after treatment must be at a level that will not endanger public health. In order to improve the effectiveness of these dips, additives may be included in the formulation. These include wetting agents, which reduce the surface tension and allow a better coating of the chemical on the crop, and acids, such as citric acid, which lowers the pH of the fungicide and can make it more effective. In some cases, the area to be protected can be targeted. In pineapples, infection of the fruit is commonly through the cut fruit stalk. Dipping this area directly after it has been cut is normally sufficient to control postharvest disease. This allows for reduced levels of fungicide application, which may thus leave a lower residue and costs less in chemical used. The effectiveness of the fungicidal treatment may be enhanced by heating the water into which the fruit are dipped. In the control of mango anthracnose, postharvest dips in fungicides in cold water rarely reduced levels

of infection; but when fungicide was applied in hot water, complete control could be achieved. The optimum recommended conditions varied between different research worker, but $500 \mu\text{L L}^{-1}$ benomyl in water at 55°C for 5 min appeared generally effective without damaging the fruit.

Sprays

Spraying fruit and vegetables with a diluted fungicidal spray postharvest may be more effective than dipping. This is because where the crop is dipped, the fungicide concentration may be reduced if the crop has been washed and is still wet. Also, fungicide may be preferentially removed from the mixture when the crop is removed. Additionally, many fungicidal chemicals are formulated in a way that they are not in solution, but in a fine suspension. This can result in a concentration gradient from the top of the tank to the bottom unless the suspension is frequently agitated. This is less likely to occur with sprays, but it is important with sprays to ensure that the crop is evenly coated with the chemical.

Knapsack sprays (Figure 56) are sometimes used postharvest, but more frequently, the spray is built into a grading line in a packhouse. In this case, the crop is passed over rollers that constantly revolve the fruit to ensure all sides are evenly exposed to the spray. The cascade applicator is a modification of this method where the fungicide is applied as a curtain of liquid under which the fruit pass. This method is good for bananas where the cut crowns are placed



Figure 56 Postharvest application of a fungicide to bananas using a knapsack sprayer.

upwards, because this is the area where the fungi are likely to attack the fruit (Thompson and Burden 1995). It is less useful in fruits such as citrus where it is important to have an even coating of chemical all over the fruit surface.

Electrostatic sprays

Breaking up the pesticide solution into fine droplets and then giving them an electric charge was first developed for field sprays. The main advantages of this system are that they give increased uniformity of application, enabling the application rates to be reduced without loss of biological activity (Law 1982). The principle on which they work is that the particles all have the same electrical charge and thus repel each other. They are attracted to earth, which in this case is the crop, and can form a thin even coat. This method was demonstrated as having a postharvest application by Cayley *et al.* (1987), who developed it for postharvest applications of various fungicides on potatoes. The tubers were passed below an electrostatic sprayer on a roller table. Subsequent work by Anthony (1991) demonstrated its effectiveness in controlling crown rot on bananas with low levels of fungicide. Application methods for bananas were similar to those described by Cayley *et al.* (1987).

Dusting

Various dusts can be applied to crops postharvest to control postharvest diseases. Wood ash is commonly used or sometimes lime (calcium hydroxide) for disease control in stored yams (Coursey 1967, Ogali *et al.* 1991, Thompson 1972a, 1972b). Fungicidal chemicals diluted in an inert carrier, such as talc, are available for postharvest use and dust formulations have been used on potatoes as they are being loaded into store. The advantage of dusts over some sprays is that the crop is still dry after application. Some vegetables may be affected by bacteria when wet, so the result of the application of water-diluted fungicides could be an increase in bacterial diseases. The disadvantage of dusts is that it is difficult to achieve complete coverage over the surface of the crop.

Fumigation

Various fumigants have been applied to crops, postharvest, for various purposes. Their use is strictly

Table 31 Effects of chemical application method on the level of crown rot disease on bananas (where 0 = no infection and 7 is crown completely covered), percentage of hands with pedicel rot and hands that were subjectively considered still marketable (source: adapted from Genay 1991. Reproduced with permission of Cranfield University)

Days in storage	Level of infection		Hands with pedicel rots (%)	Commercially marketable hands (%)	
	5	10	10	5	10
Microstat	2.4b	4.9a	66b	88bc	29a
Cascade	2.8b	4.8a	57ab	71ab	17a
Crown pads	0.8a	3.9a	36a	100c	63b
Untreated	3.0b	5.3a	70b	67a	20a

Figures followed by the same letter were not significantly different ($p = 0.05$).

controlled by legislation that is constantly changing. Sulphur dioxide is used for controlling postharvest diseases of grapes (Pentzer and Asbury 1934; Couey and Uota 1961; Ryall and Harvey 1959), litchis (Jurd 1964; Saucó and Menini 1989; Underhill *et al.* 1992; Milne 1993; La Ongsri *et al.* 1993; Tongdee 1993) and snap beans (Henderson and Buescher 1977). Acetaldehyde fumigation can be also be used on grapes (Avissar *et al.* 1989).

Paper pads or paper wraps, impregnated with diphenyl fungicide, were commonly applied to citrus fruit. The chemical vaporised slowly, protecting the fruit from fungal infection.

Sprout suppressants can be applied to root crops in store by fumigation. Tecnazene was reported to be applied as a fumigant in bulk stores, but because of the technical difficulties of application; contractors normally apply it (Burden and Wills 1989). 2-Aminobutane could be used as a fumigant in stored potatoes (Graham and Hamilton 1970). Fumigating oranges with 2-AB was also recommended for postharvest disease control (Eckert 1969).

Chemical pads

Paper pads impregnated with a fungicidal chemical were developed for the banana industry in the Windward Islands. These are called crown pads and they are used to prevent fungal infections on the cut crowns of fruit. Normally, postharvest disease control is achieved by dipping or spaying the fruit with

fungicide when it is taken to the packhouse. However, when bananas are deheaded in the field and packed directly into export cartons, it poses problems of how to protect the cut surface of the crown of the hand from infection. Applying these pads to the cut surface solved this. The pads are made from several layers of soft paper previously soaked in a fungicide (often thiabendazole) and then dried. The pad also absorbs latex given out from the cut surface and prevents it staining the banana fingers. Potassium aluminium sulphate may be added to the pads, which helps coagulate the latex. It was claimed that this system contributed to an increase of 35% in exportable quantities (Hope Mason 1984). The crown pads proved very effective in controlling crown rot (Genay 1991), and the fungicide residue levels in the banana are likely to be small (Johanson *et al.* 1989). However, the pads were difficult to apply using the technique described by the manufacturer, and in Genay's experiments, they were secured by rubber bands to ensure complete and even contact between the cut crowns and the pads. In observations by the author of commercial packs, this even contact between crowns and pads is not always achieved, so these excellent results would not always be achieved in commercial practice (Table 31). This may be reflected in the fact that crown pads are not now used as a method of crown rot control in the major banana producing countries. A British company, Harcloth of Bury Lancashire, has patented the crown pad system on bananas.

9

Safety

Fungi and bacteria will infect fresh fruit and vegetables especially during prolonged storage. In some cases, the infection may be entirely superficial but would still make the crop either entirely unmarketable or at least reduce its commercial value. In other cases, they can cause it to rot completely. Some of these organisms can produce toxic metabolic products. Those produced by fungi are called mycotoxins; those produced by bacteria are called by the name of the organism that produces them.

Church and Parsons (1995) have dealt with legislation related to safety of fruit and vegetables in a detailed review. There is considerable legislation related to food sold for human consumption. In the United Kingdom for example, the Food Safety Act 1990 states that it is an offence to sell or supply food for human consumption if it does not meet food safety requirements. In the late 1990s, the British Government set up a Food Standards Agency, one of whose concerns is food safety.

The use of modified atmosphere packaging has health and safety implications. One factor that should be taken into account is that the gases in the atmosphere could possibly have a stimulating effect on microorganisms. Farber (1991) stated that while modified atmosphere packaged foods have become increasingly more common in North America, research on the microbiological safety of these foods was still lacking. The growth of aerobic

microorganisms is generally optimum at about 21% O₂ and falls off sharply with reduced O₂ levels, whereas generally for anaerobic microorganisms, optimum growth is at 0% O₂ and falls as the O₂ level increases (Day 1996). With many modified atmospheres containing increased levels of CO₂, the aerobic spoilage organisms, which usually warn consumers of spoilage, are inhibited, whereas the growth of pathogens may be allowed or even stimulated which raises safety issues (Farber 1991). Hotchkiss and Banco (1992) stated that extending shelf life of refrigerated foods might increase microbial risks in modified atmosphere packaged produce in at least three ways:

- increasing the time in which food remains edible increases the time in which even slow growing pathogens can develop or produce toxin;
- retarding the development of competing spoilage organisms;
- packaging of respiring produce could alter the atmosphere so that pathogen growth is stimulated.

In the United States, the Food and Drug Administration's Bacteriological Analytical Manual sets out culture-based methods for detecting the presence of dangerous bacteria in food. Shearer *et al.* (2001) tested a polymerase-chain-reaction-based detection system for its sensitivity in detecting

Salmonella enteritidis, *Escherichia coli* O157:H7, *Listeria monocytogenes* and other *Listeria* species. The technique was tested on fresh alfalfa sprouts, green peppers, parsley, white cabbage, radishes, onions, carrots, mushrooms, leaf lettuce, tomatoes, strawberries, cantaloupe, mango, apples and oranges. Generally, the method was more sensitive than culture-based methods, but neither method was successful with low levels on any of the crops. However, this method allowed detection of *S. enteritidis*, *E. coli* O157:H7 and *L. monocytogenes* at least 2 days earlier than the conventional culture methods.

Micotoxins

Many microorganisms produce secondary metabolic products that are toxic. Over 150 species of fungi have been shown to be capable of producing mycotoxins and new ones are constantly being found.

Aflatoxin

The most common of these mycotoxins is aflatoxin, which is produced by *Aspergillus flavus* and *A. parasiticus* and has been shown to infect dozens of food products including groundnut kernels, coconut, wheat, rice, flour, dry beans and some leafy foods. Aflatoxins are highly toxic and carcinogenic. The presence of the fatty acid hydroperoxides, which can form in plant material either preharvest under stress or postharvest under improper storage conditions, correlates with high levels of aflatoxin production (Goodrich-Tanrikulu *et al.* 1995). Micotoxins can also be found in fresh fruit although it is much less common than in dried products. Singh and Sum-bali (2000) found *A. flavus* infection in Indian jujube fruits (*Ziziphus mauritiana*) associated with decay and that approximately 86% of the *A. flavus* isolates were toxic. Exposure of cultures of *A. flavus* to methyl jasmonate vapour was shown to inhibit toxic production. The amount of aflatoxin produced depended on the timing of the exposure (Goodrich-Tanrikulu *et al.* 1995).

Patulin

The Guardian newspaper of 11 February 1993 reported that there was considerable public

concern in the United Kingdom when apple juice in a supermarket was found to be contaminated with levels of the mycotoxin patulin (4-hydroxy-4H-furo[3,2-c]pyran-2(6H)-one). This toxin has carcinogenic properties and has a maximum permitted level of 50 µg L⁻¹ in fruit juices. Its presence results from apples or pears that have been contaminated with *Penicillium patulum*, *P. expansum*, *P. urticae*, *Aspergillus clavatus* or *Byssoschlamys nivea* and stored for too long before being processed. The toxin was found to occur in apple juice at levels 500–2500 µl L⁻¹ if it was made from rotting apples (Steiner *et al.* 1999).

In a market survey in South Africa by Leggott *et al.* (2001), 8 of the 31 fruit juice samples had patulin with concentrations ranging between 5 and 45 µl L⁻¹ with a mean of 10 µl L⁻¹. Of six whole fruit products, two samples were contaminated with 10 µl L⁻¹ patulin, and of 10 infant fruit juices; six samples had patulin concentrations ranging between 5 and 20 µl L⁻¹, but infant fruit purees showed no detectable patulin contamination. In the Cote d'Ivoire, 8 out of 44 samples of fruit juice tested by Ake *et al.* (2001) were found to contain patulin, but a level of over 50 µl L⁻¹ was found in only one traditionally manufactured sample. In 11 Australian apple and pear juices tested by Steiner *et al.* (1999), the patulin content was below the limit of 50 µl L⁻¹. In the apple juices, the patulin content was more than 20 µl L⁻¹, whereas in the pear juices, patulin could not be detected. Lavrik *et al.* (2000) showed that Sorbilen, which is an ethylene absorber, decreased storage decay and accumulation of patulin.

Edible mushrooms

As well as the fungi that infect fruit and vegetables, it is well known that a number of other fungi produce various types of poisons. The toxic mushrooms, or toadstools, may be as large as some of the edible mushrooms and some of the most poisonous species closely resemble edible species. Toxicity obviously depends on species, but can also be affected by the environment and growing conditions. Poisonous mushrooms are mostly members of the class Basidiomycetes, although some are Ascomycetes, such as the poisonous false morel (*Gyromitra esculenta*). The jack-o-lantern (*Clitocybe illudens*) is an orange yellow fungus of woods and stumps and glows in

the dark but superficially resembles the delicious edible chanterelle (*Cantharellus cibarius*). *Lactarius* has milky or bluish juice and this genus contains the edible *L. deliciosus* as well as several poisonous species. Most deaths attributed to mushroom poisoning result from eating members of the genus *Amanita*, especially the destroying angel *A. virosa* or the death cap *A. phalloides*. Sterry (1995) gives more details of toxic species, which includes many photographs and drawings. Other species that are poisonous, but may look like edible mushrooms, include:

<i>Inocybe patouillardii</i>	<i>Cortinarius orellanus</i>
<i>Inocybe fastigiata</i>	<i>Entoloma sinuatum</i>
<i>Clitocybe dealbata</i>	<i>Hypholoma fasciculare</i>

In the 5 years they studied, 1989, 1992, 1993, 1994 and 1995, there were 20–49 human cases of fungal poisoning seen annually at a hospital in Parma in Italy. The species responsible were:

<i>Agaricus hortensis</i> (2 cases)	<i>Hygrophorus penarius</i> (1 case)
<i>Agaricus romagnesii</i> (2 cases)	<i>Hypholoma sublateritium</i> (2 cases)
<i>Agaricus xanthoderma</i> (2 cases)	<i>Leccinum scabra</i> (4 cases)
<i>Agrocybe aegerita</i> (1 case)	<i>Lepiota brunneoincarnata</i> (2 cases)
<i>Amanita phalloides</i> (17 cases)	<i>Lepiota lilacea</i> (1 case)
<i>Armillaria mellea</i> (19 cases)	<i>Leucoagaricus leucothites</i> (2 cases)
<i>Boletus edulis</i> (9 cases)	<i>Macrolepiota procera</i> (1 case)
<i>Boletus satanas</i> (6 cases)	<i>Omphalotus olearius</i> (17 cases)
<i>Calocybe gambosa</i> (1 case)	<i>Pleurotus ostreatus</i> (1 case)
<i>Clitocybe candicans</i> (4 cases)	<i>Ramaria formosa</i> (4 cases)
<i>Clitocybe nebularis</i> (9 cases)	<i>Russula olivacea</i> (5 cases)
<i>Entoloma lividum</i> (33 cases)	<i>Xerocomus chrysenteron</i> (1 case)

The reasons why toxicity varied could have been that some of these fungi could have been in poor

condition or without adequate cooking when they were eaten (Bocchi *et al.* 1996, Uip *et al.* 1996).

Bacterial toxins

Escherichia coli

The coliform bacterium *E. coli* O157:H7 produces toxins and has the ability to grow on salad vegetables. This was demonstrated in a study by Abdul Raouf *et al.* (1993), where raw salad vegetables were subjected to minimal processing and storage conditions simulating those routinely used in commercial practice. Behrsing *et al.* (2000) found that packaging vegetables in an atmosphere containing 3% O₂ and 97% nitrogen had no apparent effect on populations of *E. coli* O157:H7, psychrotrophs or mesophiles. During storage for 14 days, populations of viable *E. coli* O157:H7 declined on vegetables stored at 5 °C and increased on those stored at both 12 and 21 °C. The most rapid increases in populations of *E. coli* O157:H7 occurred on lettuce stored at 21 °C. They found that an unknown factor or factors associated with carrots may inhibit the growth of *E. coli* O157:H7. The reduction in pH of vegetables was correlated with initial increases in populations of *E. coli* O157:H7 and other naturally occurring microflora. Eventual decreases in *E. coli* O157:H7 in samples stored at 21 °C were attributed to the toxic effect of accumulated acids. Changes in visual appearance of vegetables were not influenced substantially by growth of *E. coli* O157:H7, which in itself is a potential danger to consumers.

E. coli O157:H7 is also a potential problem contaminant on fresh fruit. Dingman (2000) found that four of five apple cultivars tested (Golden Delicious, Red Delicious, McIntosh, Macoun and Melrose) inoculated with *E. coli* O157:H7 promoted growth of the bacterium in bruised tissue independent of the degree of ripeness or whether they were harvested from the tree or collected as dropped fruit. When fruit was stored for 1 month at 4 °C before inoculation with *E. coli* O157:H7, all five cultivars supported growth of the bacterium. Yu *et al.* (2001) found that two strains of *E. coli* O157:H7 survived externally and internally on stored strawberries at 23 °C for 24 h and at 10, 5 and –20 °C for 3 days. The bacteria inside the fruit either survived as well or better than bacteria on the surface.

In order to control infections, hygiene and carefully handling must be paramount. Other supplementary methods have been studied. A coating on Ruby Red grapefruit and Valencia oranges prepared from a shellac formulation with morpholine to achieve pH 9 was toxic to *E. aerogenes* and *E. coli* in storage at 13 °C. The addition of the preservative paraben in the basic shellac had further inhibitory effects (McGuire and Hagenmaier 2001). Dipping inoculated fresh lettuce leaves and broccoli florets in hypochlorite solutions of 50 or 100 mg L⁻¹ for up to 2 min was not effective in eliminating *E. coli* populations although they significantly reduced the *E. coli* counts compared to those inoculated and not dipped (Behrsing *et al.* 2000). Yu *et al.* (2001) found that 3% hydrogen peroxide was the most effective chemical treatment in reducing the bacterial population. However, other work has shown that this treatment can be phytotoxic.

Inoculated apples, oranges and tomatoes that had been submerged in sterile deionised water containing 1.5% lactic acid plus 1.5% hydrogen peroxide for 15 min at 40 °C had reduced bacterial pathogens compared to those in deionised water only. Furthermore, substantial populations of the pathogens survived in the control wash water, whereas no *E. coli* O157:H7, *S. enteritidis* or *L. monocytogenes* cells were detected in the chemical treatment solution. The sensory and qualitative characteristics of apples treated with the chemical wash solution were not adversely affected by the treatment (Venkitanarayanan *et al.* 2002). Guan *et al.* (2012) showed that UV-C doses of 0.45–3.15 kJ m⁻² resulted in 0.67–1.13 log CFU g⁻¹ reduction of *E. coli* O157:H7 inoculated on mushroom cap surfaces. Graça *et al.* (2012) tested ecoinnovative sanitizer techniques on minimally processed apple slices. Their results showed that acidic electrolysed water at 100 mg L⁻¹ of free available chlorine had high bactericidal activity against *E. coli*, *L. innocua* and *S. choleraesuis*.

Salmonella

The bacterium *Salmonella typhimurium* produces toxins. Samples were taken from healthy and decayed portions of 341 fruits and vegetables collected in local supermarkets in the United States. Suspected *Salmonella* occurred in 20.2% of healthy and in 26.4% of decayed portions. The fungi *Alternaria* spp. and *Botrytis* spp. caused two-thirds of the fungal

infections resulting in the decay. In a similar analysis of 121 samples with mechanical injuries, in which some two-thirds were gouges, cuts and bruises, there were no significant differences in *Salmonella* incidence between injured and non-injured portions. Of 332 suspected *Salmonella* randomly isolated from healthy and decayed or injured portions, 5.1% were confirmed as *Salmonella* by physiological and serological testing (Wells and Butterfield 1999).

Botulism

In the United States, Draughon and Mundt (1988) investigated 34 cases of acid food botulism, of which 17 involved home-canned tomatoes. They concluded that obviously mouldy tomatoes should not be used in preparing juices and home-canned tomatoes, as mouldy tissue had a high pH and may harbour *Clostridium botulinum* and botulin toxin. Church and Parsons (1995) mentioned that there was a theoretical potential fatal toxigenesis through infections by *C. botulinum* in the depleted O₂ atmospheres in modified atmosphere packed fresh vegetables. It was claimed that this toxigenesis had not been demonstrated in vegetable products without some sensory indication, that is they have an 'off' taste (Zagory and Kader 1988, quoted by Church and Parsons 1995). However, Roy *et al.* (1995) showed that the optimum in-package O₂ concentration for suppressing cap opening of fresh mushrooms was 6% and that lower O₂ concentrations in storage are not recommended because they could promote growth and toxin production by *C. botulinum*. Sugiyama and Yang (1975) showed that with mushrooms prepacked in plastic film, *C. botulinum* not only grew on the mushrooms but also produced toxins.

Betts (1996) in a review of hazards related to modified atmosphere packaging of food indicated that vacuum packing of shredded lettuce had been implicated in a botulinum poisoning outbreak. Toxin was not formed when the inoculated packages were kept at temperatures as low as 6 °C. The results indicate that fresh vacuum-packaged enoki mushrooms do not present a botulism hazard when cultured aseptically and stored refrigerated. In the United States, botulin toxin was not detected in 148 packages from 14 independent lots by Malizio and Johnson (1999) when spores were added to the packages. Spoilage was evident before toxin formation (Johnson

and Montecucco 2008). Hauschild (1989) found that some strains of *C. botulinum* could grow at temperatures as low as 3.5 °C. CO₂ levels of over 20% can retard bacterial growth such as *Erwinia carotovora* on potatoes. The degree of retardation increases with increasing concentrations of the gas, but at these high levels, *C. botulinum* may survive (Daniels *et al.* 1985).

Measures to reduce the microbiological contamination of ready-to-use fruits and vegetables were recommended by Hguyen-The (1991) and included good manufacturing practices, disinfections of the product, standards and specifications to control the finished product. A use-by-date that limits the shelf life to a week and a storage temperature of 4 °C was recommended. These measures will reduce the multiplication of microorganisms during transport and retailing.

Listeriosis

The food-borne human pathogen, which is a gram-positive bacterium *Listeria monocytogenes* can cause the disease listeriosis, which normally has only mild influenza-like effects on healthy people, but can be fatal to pregnant women, the elderly and those suffering from chronic diseases. The bacterium can grow well in the low acid conditions found in vegetables. Problems of listeriosis are not commonly associated with stored fruit and vegetables. However, in a survey by Heisick *et al.* (1989) for the USA Food and Drugs Administration, *L. monocytogenes* was found in 21% of the samples of potatoes, 14% of radishes and 2% or less in cucumbers and cabbages. Berrang *et al.* (1989) found that it grew well on asparagus, broccoli and cauliflower in storage at 15 °C, and it even grew on asparagus in storage at 5 °C. They also found that under controlled atmosphere conditions, *L. monocytogenes* grew just as well as in air, but as vegetables can be stored for longer periods under these conditions, this can result in a longer time for the bacteria to grow. Conway *et al.* (2000) found that *L. monocytogenes* survived and its populations increased on Delicious apple slices at 10 or 20 °C in air or controlled atmospheres of 0.5% O₂ and 15% CO₂, but did not grow at 5 °C.

Shigellosis

This is a disease caused by infection with the bacteria *Shigella* spp. It is also called bacterial dysentery

and the symptoms are diarrhoea, fever and abdominal pains. Contamination has been shown to be from many sources including that of shredded lettuce (Davis *et al.* 1988).

Aeromonas hydrophila

A. hydrophila is a gram-negative bacterium that is widely spread in nature. Callister and Agger (1987) found it on virtually every type of vegetable they analysed from a grocery store. They also showed that it could grow on vegetables at temperatures of 5 °C or even lower. The bacteria can cause diarrhoea, which is usually quite mild, but more severe cases have been reported. In experiments with 'ready-to-use' lettuce and mixed salads, Guerzoni *et al.* (1996) found that the inclusion of red chicory was an inhibiting ingredient to *A. hydrophila*. They also found an antagonistic effect of *Lactobacillus plantarum* against *A. hydrophila*, but the presence of *L. plantarum* appeared to negate the inhibiting effect of red chicory.

Safety in controlled atmosphere stores

Oxygen and carbon dioxide

Low O₂ and high CO₂ can have a direct lethal effect on human beings working in those atmospheres. In Britain, the Health and Safety Executive (HSE 1991) showed that work in confined spaces, such as controlled atmosphere stores, could be potentially dangerous and entry must be strictly controlled preferably through some permit system. Also, it is recommended that anyone entering such an area should have emergency breathing apparatus as well as proper training and instruction in the precautions. Stringent procedures need to be in place, including a person on watch outside and the formulation of a rescue plan. When a store is sealed, anyone entering it must wear breathing apparatus. Warning notices should be placed at all entrances to controlled atmosphere stores and an alarm switch located near the door inside the chamber in the event that someone may be shut in. There should be a release mechanism so that the door can be opened from the inside. When the produce is to be unloaded from a store, the main doors should be opened and the circulating fan run at full speed for at least an hour before unloading is commenced. In

the United Kingdom, the areas around the store chamber must be kept free of impedimenta in compliance with the appropriate Agricultural Safety Regulations.

O₂ levels in the atmosphere of 12–16% can affect human muscular co-ordination, increase respiration rate and affect their ability to think clearly. At lower levels, vomiting and further impediment to co-ordination and thinking can occur. At levels below 6%, human beings rapidly lose consciousness, and breathing and heartbeats stop (Bishop 1996). The limits for CO₂ levels in rooms for human occupation was quoted by Bishop (1996) from the Health and Safety Executive, publication EH40-95 *Occupational Exposure Limits*, as 0.5% CO₂ for continuous exposure and 1.5% CO₂ for 10 min exposure.

Great care needs to be taken when using modified atmosphere packaging containing 70 or 80% O₂, or even higher levels, because of potential explosions.

Ethylene

Ethylene is used in fruit ripening rooms. It is a colourless gas with a sweetish odour and taste, has asphyxiate and anaesthetic properties and is flammable. Its flammable limits in air are 3.1–32% volume for volume and its autoignition temperature is 543 °C. Care must be taken when the gas is used for fruit ripening to ensure those levels in the atmosphere do not reach 3.1%. As added precautions, all electrical fitting must be of a 'spark-free' type and warning notices relating to smoking and fire hazards must be displayed around the rooms.

Toxicity of packaging material

Another safety issue is the possibility that the plastic films being used in modified atmosphere packaging are toxic. Schlimme and Rooney (1994) reviewed the possibility of constituents of the polymeric film used in modified atmosphere packaging migrating to the food that they contain. They showed that it is unlikely that the polymerised constituents would be transferred to the food because of their high molecular weight and insolubility in water. All films used can contain some non-polymerised constituents, called monomers, that could be transferred to the food and the Food and Drugs Administration in the

United States, and also the European Community have regulations related to these 'indirect additives'. The film manufacturer must therefore establish the toxicity and extraction behaviour of the constituents with specified food simulants.

Packhouse safety

Clarke (1996) reviewed safety and hygiene of the workforce and suggested the following. In some countries, there are strict laws to control the health and safety of all workers and these of course must be adhered to. In the absence of such laws, one could use the principles laid down here as a guide.

'Clothing should be provided that is suitable for each task. Most workers would be engaged on the inspection or packing, which would require simply an overall, a cap or hat and probably rubber gloves if preferred. The overall would often be of the coat type with a zip or button front. Trousers or skirts would often be open to personal choice, although some employers may well provide trousers for work in what is often a cool, draughty and elevated position. Shoes would also commonly be provided with a firm, non-slip sole and sturdy foot support. Boots would not normally be necessary but the lighter, ladies fashion shoes and high heels, etc. must clearly be avoided.

The start-up of all machines is a procedure that can lead to danger if not done to a set order. Firstly, a warning hooter should sound, giving everybody ample chance to stand clear of the machines, and then after a few seconds of the hooter, the whole line should start-up. This could however lead to unnecessary overloads on the electricity supply system as all motors would reach peak demand at once. It is just as acceptable to start all motors in reverse order with the last machines in the production line starting up first and the others in progression going back down the line to the first machines. The first motors are likely to be loaders and feeding belts, so it is important that all the line is fully operational before any crop arrives.

In case of danger on any part of the process line, there should again be close adherence to the regulations that govern all electrical machines for health and safety at work. For example, 'Every electrical motor shall be controlled by an efficient switch for

starting and stopping so placed to be easily worked by the person in charge of the motor. In every place in which machines are being driven by any electric motor, there shall be a means at hand for either switching off or stopping the motor/machine if necessary to prevent danger'. This would normally be achieved by the provision of a large red button placed at convenient positions all along the process line.

All other regulations such as insulation should be taken care of by the machine manufacturer.

Walkways and forklift truck ways should be clearly marked on the floor in bright yellow paint so that both workforce and visitors are not likely to stray into the danger zone. Forklift trucks should be equipped with a hooter to warn anyone in danger and should be powered by gas to avoid fumes.'

10

Marketing and transport

Marketing

Dixie (1989) gave the following two definitions of marketing. 'The series of services involved in moving a product (or commodity) from the point of production to the point of consumption.' 'Marketing involves finding out what your customers want and supplying it to them at a profit.' Marketing of perishable crops becomes increasingly important as the standard of living of consumers increases, because they require higher, more consistent quality as well as fruit and vegetables when they want it, not necessarily when the fruit and vegetables are in season.

In many countries, the production of fresh fruit and vegetables is currently lower than the market requirement. These normally result in a seller's market, where the farmer can sell all the crops that are grown, and there may be little incentive to supply high-quality crops on the market. This happens in less developed countries. In other societies, crop production, or potential crop production, is greater than the demand. The effect of this, in European markets, for example, has not necessarily reduced the price of the crops as might have been expected, but increased the quality of the crops being offered to the consumer. It is not unknown for fruit and vegetables to be destroyed in order to maintain market prices. This can even happen after the crop has been harvested and packed for the market. In industrialised countries, the farmer is increasingly studying the market

to determine its requirements. An example of this is organic fruit and vegetables that usually command a premium market price. However, their higher cost of production has resulted in production not always being economic and there are groups lobbying for government subsidies.

Where markets are not well-regulated, this has led to fluctuating supplies of crops such as vegetables. This is because the farmer may see a particular crop is commanding a high price on the market because of undersupply. While the farmer changes his production to this crop, other farmers see the same opportunity and also change resulting in an oversupply. This can lead to low prices and farmers stopping to grow that crop leading to a shortage, and the cycle repeats itself. This has led to the establishment of commodity marketing boards to regulate supply to the perceived demand. There are several cases where these marketing boards have had major effects on produce marketing, for example the New Zealand Apple and Pear Board and Agrexco from Israel, but many others have had limited success in the perishable crop sector.

The flow of fruit and vegetables from the producer to the consumer is not simply governed by the market forces of supply and demand. These forces are tempered, modified and controlled by import duties, quotas and other trade barriers. The General Agreement on Tariffs and Trade (GATT) was first implemented in 1948 as a mechanism to promote free and fair trade between its member states, and

several rounds of negotiations were carried out in the following years and rules that governed international trade were formulated. The Uruguay round of GATT began in 1986 and was signed in April 1994 in Marrakech. This opened up trade throughout the world, including that in fruit and vegetables. The Uruguay round of GATT led to the creation of the World Trade Organisation (WTO) to reform and police international trade agreements. This put an onus on the more than 100 states that signed the agreement to reform both their internal and external trade policies to open up international trade. However, the rules are complicated and allow for states and trading blocks to subsidise production and impose tariffs on imports to protect their own farmers.

There are many cases where trade is not a 'level playing field' and it is often to the detriment to farmers in developing countries and the benefit of farmers in the more wealthy countries. Such liberalisation of trade can also lead to specific difficulties for some producer countries. There were riots in India against the WTO rules. The banana industry in the French West Indies, the Canary Islands and the African Caribbean and Pacific (ACP) countries has had preferential access to European Union countries. Many of these ACP countries have vulnerable economies, which are dependent on banana exports, and because of factors such as comparatively high labour costs or lower capital investment, they are unable to compete with other countries on price. The WTO ruling against these trade preferences between ACP countries and the European Union has been a potential source of problems in these fragile economies. The WTO ruling in 1997 against trade preferences between ACP countries and the European Union has been a potential problem in these fragile economies. The European Union is the principle importer of bananas in the world and a settlement of the disputed WTO ruling over tariffs on imports into the European Union was achieved in December 2009. The WTO brokered an agreement with the non-ACP banana producers and the United States that ACP suppliers can continue to export to the European Union duty-free and quota-free under the 2008 Economic Partnership Agreements. The European Union will continue to apply a duty on the import of non-ACP bananas called the Most Favoured Nations Duty. There are some provisos with the regulations but,

in brief, they are that the non-ACP banana exports to Europe will attract progressively reducing tariffs until 2017.

Marketing systems can be considered on their structure, conduct and performance. Structure relates to their relative size, number of institutions and the various functions of the participants. Conduct is described by the level of control by government and the level of competition of market participants regarding the product, price and promotional strategies. The performance can be measured in several ways, but the most common one is by its efficiency. Profits, turnover, innovation and research and development may measure efficiency. These three factors are interdependent in that each will affect the way the market is structured and the way business is conducted and both in turn will affect its performance.

Many perishable crops are seasonal and their value, or selling price, varies throughout the year. Orderly marketing can be achieved in certain cases by storing the crop from the harvest season to the season of scarcity. Many different marketing systems have been used in many developing and industrial countries. However, the problem remains of getting fresh fruit and vegetables from the producer to the consumer with the minimum of loss in quality or quantity, at the time the consumer desires them and at minimum cost. All marketing systems have some flaw in them, and many have been started and have had to close after periods of operation. All these systems are constantly changing and evolving to suit changing market and political situations.

Marketing systems

Direct marketing

The simplest system is where the farmer sells directly to the consumer. For this, the consumer may call directly at the farm. In many countries, this has led to the development of farm shops where the farmer harvests the crop and offers it for sale. This is often supplemented by purchasing crops from wholesale markets to increase the range of crops offered. 'Pick-your-own' is where the farmer grows the crop and customers harvest it themselves and pay the farmer for the quantity they have harvested.

Middlemen

Middlemen may visit the farm to purchase from the farmer. They will then resell the produce to a wholesaler or retailer. In many situations, the middlemen have their own labour force, which relieve the farmer from having to harvest the crop; he simply sells the crop by area or weight harvested. An example of this is the Kissan Company in Bangalore in India. They are major processors of mangoes, and they have a team of workers whose function is to go from plantation to plantation harvesting fruit that is then sent directly to the factory. In many less developed countries, the farmer harvests the crop, transports it to market and then sells it. In many cases, these sales are at the retail level and can take the farmer a considerable amount of time to sell only a small quantity.

Direct to retailer

In industrial countries, many farmers, particularly those on a large scale, sell directly to supermarkets. This is commonly on a contract basis and can be a very convenient way of marketing for the producer or importer. The supermarkets, however, have stringent quality requirements and times of delivery. Only the best organised and efficient farmers who are forward thinking are consistently successful in these markets. In the United Kingdom, with overproduction of many crops, some supermarket suppliers fail.

Wholesale markets

Specialist wholesale markets have been established in towns and cities throughout the world to assist in marketing fresh fruits and vegetables. Many of these have been in existence for centuries. These consist of groups of middlemen who purchase produce, often from the producer, the producer's cooperative or importer (sometime through brokers) and sell the produce to a retailer. The situation is usually more complicated with wholesalers selling to secondary wholesalers or to exporters (particularly in some developing countries) or directly to the consumer. Fresh produce is mainly highly perishable and has a fragmented production base, which makes it extremely difficult to standardise quality and production specifications (Henderson 1993). Wholesaling of fresh produce should minimise the number of transactions and reduce the stocks required and

be involved with price discovery, minimising of wastage as well as assembly, stockholding, financing, standardisation and breaking bulk (Sturgess 1987). The demand for fresh produce is relatively inelastic in that large price fluctuations create only small fluctuations in demand. This can result in prices being unstable and the need for buyers and sellers to have frequent and close contact (Henderson 1993). In United Kingdom, at the Covent Garden market, the average mark-up for wholesaling services was about 18% of the value of primary production at the farm gate or the dockside (Sturgess 1987).

Retail markets

Retail outlets vary from carts on the streets, through established open markets (Figure 57) and small greengrocer's shops to multiple retailers called supermarkets. Throughout the world, this diversity of retail outlets has been retained, but the multiple retail sector has constantly increased its market share. This is due to various factors including the consistent quality of produce and convenience of purchasing the weekly shop in one place. Retail stores were traditionally supplied by the retailer going to the wholesale market early in the morning and purchasing the items required. With the multiple sector, various systems have been put in place to obtain supplies. These usually involve the produce being delivered to a distribution centre where crops are held and sometimes graded and sent to individual retail outlets. In Britain, there has been considerable debate



Figure 57 A retail fruit and vegetable market in Bedford, UK. See colour plate section.

about supermarkets obtaining locally produced fruit and vegetables. Some progress has been achieved but they often have difficulties in maintaining consistent supplies of sufficient quality.

State marketing

In the past, in some communist countries the state was responsible for the marketing of fruits and vegetables. In the People Democratic Republic of Yemen before unification with the Yeman Arab Republic, this system prevailed. The result was that harvesting and handling systems were very inefficient and delivered poor quality produce to the consumer. In China, the marketing of fresh produce was entirely in the hands of the state until the mid 1980s. After that time, wholesale and retail markets were allowed to evolve. It is interesting to observe that this system involved middlemen with lorries going to the countryside and bringing the produce to places in the towns and cities where the produce were offered for sale. In 1986, the Dazhongsi Farm and Sideline Products Wholesale Market was established in Beijing. This provided a site in which wholesale trade could take place and by 1993 had 10,000 customers and total annual sales of 58 billion kg. It is the largest of the four wholesale markets in Beijing and is operated by the local government and charges 2% on sales to meet its operating costs. They also pay an additional 3% in tax to the Government.

Dutch auctions

The Centraal Bureau van de Tuinbouwveilingen in Nederland operates a special type of wholesaling. These wholesale auctions are owned by growers who produce, harvest, grade, prepare, pack and send the produce to the auction (Hill and Selassie 1993). Auction staff is responsible for quality and assembling the produce into suitable quantities for sale. The lots of produce are offered for sale by the movement of the arm of a clock that moves from a high price to progressively lower prices. Prospective purchasers can stop the clock at any point and then become the owner of that produce at the price on the clock at the time it was stopped. Computerisation has been developed in controlling the auction clock and linking the clock with the auction accounts department

and distribution. Clocks from several auctions can be displayed together with information on supply and demand (Crawford and Selassie 1993). The marketing system in Holland often leads to high wastage levels of good quality produce. This is done to keep prices high so that where some lots do not achieve a predetermined minimum price, those lots are taken off the market and destroyed. A mean price is taken for all the produce of that type which has been sold at that time, and the owners of the produce that has been destroyed receive the same proportional share as those whose produce was sold.

Panels

Many organisations market their produce through panels. These are common in the United Kingdom and are fruit and vegetable importing companies who are responsible for marketing and distribution of a product or group of products from one source. For a company to be a panel member, it must reach the standards required by the supplier. An example of this would be the citrus panel that is supplied by Outspan. Outspan would invite a company to join their panel whom they feel have sufficiently high standards, distribution network and contacts within the industry. The panel member then has the responsibility to supply retailers. In most cases, the supermarket sector of the fruit and vegetable retailing industry deals through panellists rather than directly with the marketing board. The supermarket may prefer to work in this way because it provides flexibility so that if the produce does not achieve the required standard, it can easily be returned to the panel member to be retailed elsewhere or otherwise disposed of. The panellists receive a commission for the services that they supply. This system does extend the marketing chain and may change or be modified to meet competition in a changing market situation.

Cooperative marketing associations

Cooperative marketing is where a group of farmers associate to market their produce together. There are many examples of successful marketing cooperatives. East Kent Packers in England was formed by a group of local apple and pear producers owned by the grower members, but it unfortunately went out of business. They provided very sophisticated

controlled atmosphere storage facilities and grading and packing equipment. Members grew and harvest their crops and sent them to East Kent Packers where they are graded, packed and sent to market or placed in storage for later marketing. The stores and packhouse were used for other crops on a contract basis when they were not required for members' fruit, which provided additional income for members. Growers' cooperatives have the advantages for small- to medium-sized farmers of increasing the quantity of produce to be marketed, thus improving continuity of supply, bargaining position and the employment of special marketing techniques and staff. In some cases, marketing and related activities are supported by statutory bodies such as marketing boards or export boards.

Fair trade

In spite of the creation of the World Trade Organisation, there is much international trade that exists to the benefit of developed countries at the expense of less developed countries. Twenty percent of the world's population had 82 times the income of the bottom 20%. There are many organisations that have been set up to address this imbalance of trade and income. Fair Trade is a non-government organisation (NGO) that is over 40 years old. It has a charity background but commercial companies are also involved. It publishes a set of values in which trade takes place. Other objectives are to give value for money and good quality so there is something in it for consumers. Its objective is sustainability 'in it for the long term', so that it provides a stable situation for the grower.

The main product with which it is involved is coffee marketed as Café Direct. Fair Trade is a movement not a brand, but becoming a brand is their aim in United Kingdom especially with Café Direct. Café Direct has been in existence for over 10 years and is sixth largest supplier of coffee in Britain. It has suppliers of 1.5 million growers and their families. It comes from a higher cost base; therefore, it charges a premium for its brand. Much of this is passed to the grower who either invests the premium into his or her own cooperative or uses it to improve his or her standard of living. In the United Kingdom and Japan (where the People Tree brand is trendy and cool and good with young people), many people are conscious of it, but in Spain and United States, they are not.

Fair Trade has become increasingly concerned with the marketing of bananas and supports a cooperative in Ghana. A fruit sticker is attached to each cluster of fruit and a premium price is charged to the consumer. Most of this is passed onto the producer, so those small farmers receive a better income than they would if they marketed their fruit in other ways.

Market analysis

There are two basic systems that can be applied to the marketing of fresh fruit and vegetables. The first is simply to market what farmers can produce. This system is very common in developing countries and usually is well founded and has evolved over generations. Supply and demand for the crops are not always in balance and there can be large seasonal fluctuations in both quantities available on the market and the price received for the crop. In extreme situations, it may not be worth harvesting the crop. Many ways of overcoming this situation have been developed including storage to link periods of excess supply and market promotion to increase the demand at that time. This marketing system can be a major problem where new markets are being developed. This is particularly important where export development or a processing industry is planned. The alternative is market analysis. This means looking at the proposed market and producing for that market. This can involve producing specific varieties of specific crops to a defined quality and predetermined schedule. It usually also involves management and postharvest practices which are required by the market. One analytical procedure, which can be used to assess the market potential, is SWOT analysis (strengths, weaknesses, opportunities and threats). The stages are to look first at the planned business to determine what it can do or be developed to do best. When this has been decided, the difficulties that are likely to be encountered in the proposed business must be estimated and ways in which these weaknesses can be overcome must be formulated. The market must be studied in detail to determine current supply and demand factors by studying previous market data and picking up possible trends of what the market might be in the future. This will also include determining any legislation governing standards and which varieties of crop receive the best prices and at what time of the year.

Market situations, especially on export markets, are constantly changing and it is important to know what competitors, or potential competitor, are doing or planning to do. This should be taken into account when planning the business. Crop production is subject to environmental conditions and sometimes pest and disease infestation and in developing countries the supply of materials that are necessary for production and postharvest operations.

Retaining the crop in optimum condition throughout the marketing chain also becomes increasingly important in ensuring that marketing is profitable. A major contributor to this is the means of transporting the crop from the producer to the consumer.

Branding

At one time, branding seemed to be just related to tough looking men in leather using a red hot iron on cattle, but the concept has now become a major occupation of clever people putting a logo or name into the mind of people. The subject of branding of fresh fruits was reviewed by Best (1993). In its simplest form, a brand can be defined as 'a name, term, symbol, design or all of these intended to identify and differentiate goods and services one from another' (Kotler 1991). However, according to Davies (1992), brands are more than just a 'label to differentiate' and are in fact 'a complex system that represents a variety of ideas and attributes separate and distinct from the product, each capable of undergoing change independently of each other'. Murphy (1990) defined a brand as 'a trademark which, through careful management, skilful promotion and wide use, comes in the mind of the consumers, to embrace a particular and appealing set of values and attributes, both tangible and intangible. It is therefore much more than the product itself; it is much more than merely a label. To the consumer, it represents a whole host of attributes and a credible guarantee of quality and origin. To the brand owner it is in effect, an annuity, a guarantee of future cash flows'. He identifies the brand as the output of a management process which invests resources to develop assets that are increasingly being recognised on company balance sheets and being assessed for their profit earning capability.

Increasingly, the brand is seen not as a thing that people involved in marketing do to their product

but as a relationship that they develop with their customers. de Chernatony and McDonald (1992) suggested that successful brands are 'an identifiable product, service, person or place, augmented in such a way that the buyer or user perceives relevant unique added values which match their needs most closely. Furthermore its success results from being able to sustain these values in the face of competition'. The success of brands stems from the management of the entire marketing mix to create an augmented commodity form of a product that has meaning to the consumer beyond the functional product. Although brands are most commonly associated with products, and in particular fast moving consumer goods, they can be developed for a wide range of market offers including services, countries and people.

These definitions trace the development of the understanding of the brand over time and reflect the changing emphasis of branding from physical products to services such as financial services. Their emphasis on the non-functional aspects of branding appears to be particularly relevant to the fresh fruit industry.

Consumers are aware of brands in the fresh produce industry. In a survey reported by Best (1993), prompt awareness by people in the United Kingdom for brands in the citrus industry were:

Jaffa	95%
Outspan	93%
Sunkist	54%
Morocco	30%
Florida	24%

An understanding of the parts which comprise a brand is paramount to understanding why some 'products get commodity prices, giving them low margins, and other brands get the commodity price plus whatever the brand is worth beyond the product' (King 1984). Levitt (1986) described the brand as having several components, which might be applied to a fresh fruit brand as follows:

- Core attributes that meet the basic needs of the consumer, for example an apple.
- Generic attributes that exist in the commodity form of the product, delivering the functional attributes that meet the basic need of consumers. For example, the Cox's Orange Pippin variety, ripe, blemish free, graded, labelled, available in stores.

- Expected attributes where the generic form is tailored to needs of specific customers. For example, Cox's Orange Pippin grown in England, tasting like English Cox's Orange Pippin, available in stores servicing the targeted consumer segment, labelled English Cox Apples.
- Augmented attributes meeting consumers' non-functional needs. For example, assurances of taste and quality of traditional Cox's Orange Pippin, reassurances that English Cox's Orange Pippin can only be grown in England, and that English Cox's Orange Pippin represent an English way of life.
- Potential attributes that are the limitless enhancements of the brand, often intangible and emotional, which underlie its extended life. For example, upgrading of the cultivar to include new features, extension of the Cox's Orange Pippin image to other products such as jams, and juices. Keeping adjustments in promotions to keep in touch with perceived English self-image of the main consumer segment.

National transport

This is the transfer of produce from the farm to the place where it is to be offered for sale. The system varies in both less developed countries and the industrialised countries from simply packing the produce in some kind of vehicle for transport, to having comprehensive environmental control around the crop. The reasons for selecting a particular type of transport may be related to:

- special characteristics of the crop
- its value
- what is available
- what is most appropriate.

Where crops are moved short distances, quickly from the field to the market or directly to the consumer, it is usually unnecessary for most crops to need any temperature management or other controlled conditions. This simple kind of transport can appear cheap, but it may result in high crop losses due to physical damage. In a study of banana transport in the Sudan, it was shown that bunches packed in lorries padded with banana leaves and transported from the field to the ripening rooms had extremely

high levels of damage. Packing the bananas in plastic boxes for transport greatly reduced these losses (Silvis *et al.* 1976).

In a study of sweet potatoes by Tomlins *et al.* (2000) in Tanzania, the handling and transport system resulted in up to 20 and 86% of roots with severe breaks and skinning injury, respectively, and a reductions in market value of up to 13%. The most severe impacts occurred during unloading and loading from road vehicles and ships. However, skinning injury and broken roots were correlated with a large number of minor impacts.

International trade

From the middle ages, small quantities of dried spices, fruits and beverage crops were traded internationally mainly from the East to Europe, but these were relatively small quantities and were expensive. International trade in fresh fruits and vegetables was scarce. In the late 18th century, citrus fruits were traded throughout Europe, but were mainly from orchards in Spain and Portugal. At that time, the human populations in Europe were comparatively small and mainly involved in some aspect of agriculture or the service sector and there was little incentive for international trade. In the 19th century, the industrial revolution stimulated manufacture and the trade in raw materials to service the industry. This was particularly so in Britain, where the population rose from a fairly stable level of some 9 million in 1801 to over 36 million by 1911. This stimulated the demand for food and attracted imports. Initially, these were mainly from other European countries, but with the development of steam ships, they increasingly came from further afield. Dietary habits also changed and the market for fruit and vegetables increased. This demand was supplied by local producers and led to the development of such technologies as producing crops in heated glasshouses, but also to an increasing extent by imports. This was especially stimulated when the British Government abolished the import duty on fruit in 1860. Citrus fruits were the main import, but apples, cherries, grapes, melons, pears and plums were also traded. Pineapples were exported from the West Indies to Britain from 1842 in schooners. In order to supply out-of-season fruit, shipments of apples, grapes and other fruits were being made

from South Africa to Britain from 1888 with mixed results. The first export shipment of bananas was from Jamaica and was reported to be 500 stems to Boston in 1866 which took 14 days and the fruit were said to have been sold at a profit (Sealy *et al.* 1984). There was no indication of temperature control during this or subsequent shipments in the latter part of the 19th century. In 1879, steam ships as well as schooners were being used to transport fruit from the Caribbean Islands and Central America to the United States.

International sea transport of perishable foodstuffs using refrigeration began in the latter part of the 19th century. The use of cooling for transport began in 1873 or 1874 using ice through which air was circulated by fans on shipments of meat from the United States to Britain and this developed into a regular trade in 1877 when mechanical refrigeration was used on the ships. The first records of refrigerated shipment of fresh fruits and vegetables were in 1880 from Italy to Britain and included pears and peas. In 1901, the vessel Port Morant carried 23,000 stems of bananas from Jamaica to Britain using mechanical refrigerated holds for the company Elder and Fyffes (Sinclair 1988).

Cold chain

Cold chain transport, where the crop is precooled directly after harvest and kept at a constant temperature throughout the marketing chain, is being increasingly practised in both industrial and non-industrial countries. The system involves a high capital expenditure but ensures a high level of quality maintenance and a reduction in physical losses of crops. In Britain, the major retailers (supermarkets) have distribution centres where growers deliver their crops. The supermarket will have agreed price, quantity and quality with the producer. They will also specify the precise time at which it must be delivered and the temperature of the crop at the time of delivery. A well-run cold chain is therefore essential in order to achieve these requirements.

Transport by sea

For export, fresh fruit and vegetables are largely transported in temperature-controlled cargo space

Table 32 Costs (other than labour) and returns in Trinidad and Tobago Dollars of a shipment of mangoes of the cultivar Julie shipped from Trinidad to Britain at 13 °C taking 10 days (source: adapted from Thompson 1971b)

Expenditure		T&T \$
Cost of fruit per carton		1.60
Cost of carton		0.71
Refrigerated sea transport		1.34
Total		3.65
Income		
Grade 1	53%	12.24
Grade 1	19%	3.96
Grade 2	19%	3.60
Wastage	9%	0.00
Total		19.80

in either 'break bulk' or containers such as 'reefers', porthole or ventilated types. In trial shipments of mangoes from the West Indies to Britain, it was shown that the fruit was in good condition on arrival and was profitably sold (Table 32).

Refrigerated containers were first introduced in the 1930s, but it was only in the 1950s that large numbers were transported on ships. Their use was on the West Coast of the United States to Hawaii. In the late 1960s, the porthole container was introduced. Different operators developed different specifications and sizes of the various types of container. This was particularly evident in their length, which varied from 17-, 20-, 24-, 35- and 40-feet long. This variation prevented interchange of containers between different operating lines. Currently, only a small part of the world supply of containers deviate from the standard 20- and 40-foot lengths recommended by the International Standards Organisation in 1967. The first purpose-built container ship was completed in 1969 that had a capacity of 1300 twenty foot equivalent units and during succeeding years they have increased in capacity. Numbers have also increased, for example over the period 1970–1988, the world container fleet has increased from 195,000 twenty foot equivalent units to 2,869,000 twenty foot equivalent units.

Break bulk

Break bulk refers to a system of transport where individual boxes or pallets of produce are stacked

directly in the hold of the ship. Bananas account for some 35% of the fresh produce transported in this way. Most produce is palletised before shipping and maintained in this condition throughout the marketing chain; in some cases, this is right up to the retail outlet. Palletisation reduces handling and therefore labour costs and damage to produce. The standard international pallet is 1000 × 1200 mm on which produce is commonly stacked to some 2100 mm high. The holds of ships are commonly 2200 mm high and reefers the same or higher so that pallet loads can fit in with an adequate clearance to allow for air circulation. Boxes should be secured on the pallet with edging strips so that they do not move during transport. During winter when the seas are rough, there is a considerable increase in the level of damage to boxes and to the fruit they contain. Dunnage or inflatable bags may be placed between pallets to improve air circulation and temperature control.

Reefer containers

A large and increasing amount of fresh fruit and vegetables is transported by sea freight refrigerated (reefer) containers (Thompson and Stenning 1994). Reefers are insulated containers which have their own individual refrigeration units. They are built to International Standards Organisation specification which specifies that they must be sufficiently strong so that they are capable of holding 30 tonnes and withstand a vertical load of up to nine containers stacked above it. These containers have about 70 mm of insulation in the walls, generally polyurethane foam. A new insulated container will have a heat leakage of about 22 W K⁻¹, but some containers designed solely for the carriage of fresh fruit will have thinner insulation with a heat leakage of around 35 W K⁻¹ (Heap 1989). The foam almost always contains low conductivity halocarbons to improve performance. Insulation efficiency reduces with time, due to loss of halocarbons and moisture ingress, by about 3–5% per year (Heap 1989). Sizes vary but commonly used international sizes are given in Table 33.

Operating costs of containers is usually much higher than break bulk, but apparently it can also be lower as it depends on the journey (Table 34). Bananas are the most important fruit that is transported by sea freight and almost all international

Table 33 Sizes and capacities of reefer containers (source: adapted from Seaco Reefers)

Type	External dimensions	Internal dimensions
<i>20 foot (RM2)</i>		
Length	6,096 mm	5,501 mm
Width	2,438 mm	2,264 mm
Height	2,591 mm	2,253 mm
Capacity	28.06 m ²	
Tare	3,068 kg	
Maximum payload	21,932 kg	
ISO payload	17,252 kg	
<i>40 foot (RM4)</i>		
Length	12,192 mm	11,638 mm
Width	2,438 mm	2,264 mm
Height	2,591 mm	2,253 mm
Capacity	59.81 m ²	
Tare	4,510 kg	
Maximum payload	27,990 kg	
ISO payload	25,970 kg	
<i>40 foot (RM5)</i>		
Length	12,192 mm	11,638 mm
Width	2,438 mm	2,264 mm
Height	2,896 mm	2,557 mm
Capacity	68.03 m ²	
Tare	4,620 kg	
Maximum payload	27,880 kg	
ISO payload	25,860 kg	

Table 34 A comparison between the c.i.f. costs of international transport of bananas communicated to UNCTAD in 1981 in US\$ per carton (source: adapted from Sinclair 1988)

Journey	Break bulk (\$)	Containerised (\$)
Central America to North America	5.64	5.95
Central America to Europe	7.63	7.41
French West Indies to France	8.42	8.23

trade in bananas is still carried out using break bulk. The trade from Martinique and Guadeloupe in the Caribbean is heavily subsidised through the EU Common Agricultural Policy and there they use containers for bananas. The relatively new industry from the port of Tema in Ghana uses containers, but this reflects the scale of operation and the difficulty in securing break bulk transport. For the growers in Ghana, it means that the only way the industry can be viable is by obtaining subsidised prices mainly through the Fair Trade Organisation.

Porthole containers

Porthole containers, which are also called Conair containers, are insulated containers that do not have their own refrigeration unit. Instead they have two 10 cm diameter ports, which can be connected to an external refrigeration system via a flexible hose. They are used in ships where the containers are plugged into the ship's refrigeration system. They may also be plugged into a unit at the port to cool the produce while awaiting transport. The advantages of this type of system are that the rental costs on the containers are lower and the units can be cooled more quickly because of the larger refrigeration capacity from the ship's system. Disadvantages are that special facilities are required both at the port and on the ship. Refrigeration can only be started when the container has reached the port and not at the packhouse where it may be loaded. With reefer containers, a diesel generator may be fitted or attached to the container so that its contents may be cooled directly after it has been loaded.

Ventilated containers

Ventilated containers are standard metal containers that have no insulation or refrigeration unit but have some kind of ventilation system. This may simply be square apertures along each of the long sides with downward pointing fixed louvers. A row is situated near the top and another row near the bottom down each of the long sides of the container. Ventilation is passive using natural convection currents. A more elaborate system has extractor fans installed high up on the doors of the container. These usually have the same ventilation of the passive system but with just one row of apertures towards the bottom of the container on each of the long sides. The attraction of these types of container is their low rental cost compared to reefers. SeaVent used a passively ventilated container filled with 17½ of green coffee in extremes of temperature and humidity in a simulated trial of the conditions that would be encountered during transport from the tropics to Europe. It was found that the coffee was in perfect condition, and this method is now being used on a large commercial scale throughout the world. They are also used for transport of crops such as potatoes and onions even for long distances such as from Australia to the United Kingdom.

Modified atmosphere containers

Modified atmosphere containers have been used for several decades with varying degrees of success. Transfresh of Salinas in California build containers that are designed to be gas-tight and that have an aluminium track fitted around the door to which is fitted a plastic curtain to eliminate leakage through the door. After loading, the container is sealed and the required gaseous atmosphere is injected through purging ports.

Controlled atmosphere containers

Controlling the levels of some of the gases in reefer containers has been used for many years to increase the marketable life of fruits and vegetables during transport. Many commercial systems have been manufactured. Champion (1986) reviewed the state of the art of controlled atmosphere transport as it existed at that time. He listed the companies who cooperated in the production of the paper, which gives some indication of the large number of companies who were involved in the commercial application of this technology, as follows:

- AgriTech Corporation, USA
- CA (Container) Systems, UK
- Finsam International, Norway
- Franz Welz, Austria
- Fresh Box Container, West Germany
- Industrial Research, Netherlands
- Synergen, UK
- TEM, USA
- Transfresh Corporation, USA
- Transfresh Pacific, New Zealand.

Many of those companies have since gone out of business and others have been started. Champion (1986) also defined the difference between controlled atmosphere containers and modified atmosphere containers. The latter has the appropriate mixture injected into the sealed container at the beginning of the journey with no subsequent control, which means that in containers being used to transport fresh fruits and vegetables, the atmosphere will constantly change during transport. Controlled atmosphere containers have some mechanism for measuring the changes in gases and adjusting them to a preset level. Dohring (1997) stated that the world fleet has increased fourfold since 1993 and in 1997

consisted of 38,000 reefer containers with only some 1000 providing control of humidity CO_2 and O_2 , that is controlled atmosphere containers.

Dohring (1997) claimed that 'avocados, stone fruit, pears, mangoes, asparagus and tangerine made up over 70% of container volumes in recent years. Lower value commodities e.g. lettuce, broccoli, bananas and apples, make up a greater percentage of the overall global produce trade volumes but cannot absorb the added CA costs in most markets.' Previously, Harman (1988) had suggested the use of controlled atmosphere containers for transport and storage for the New Zealand fruit industry, but there has been only limited uptake. Lizana and Figueroa (1997) found that long distance sea transport for 35 days of Hass avocado fruits from Chile to the United States was feasible in refrigerated controlled atmosphere containers. They found that the best controlled atmosphere storage combination for Hass avocado fruits was at 6°C and 90% r.h. with 5% CO_2 and 2% O_2 .

Gas sealing

The degree of control over the gases in a container is affected by how gas-tight the container is; some early systems had a leakage rate of $5\text{ m}^3\text{ h}^{-1}$ or more, but current systems can be below 1 m^3 (Garrett 1992). Much of the air leakage is through the door and fitting plastic curtains inside the door could reduce the leakage, but they were difficult to fit and maintain in practice. A system introduced in 1993 have a single door instead of the double doors of reefers containers, which are easier to make gas-tight. Other controlled atmosphere containers are fitted with a rail from which a plastic curtain is fitted to make the container more gas-tight.

Gas generation

Controlled atmosphere containers are gas-tight, so the respiration rate of the fruit will eventually produce lower O_2 and higher CO_2 levels. Ilinski *et al.* (2000) found that for the apple cultivars Antonovka, Martovskoe, Severni Sinap and Renet Chernenko, the CO_2 concentration in controlled atmosphere containers reached 15–19% and O_2 was reduced to 0.4–0.8% within 3–3.5 days. This may be too slow and therefore the systems used to generate

the atmosphere in the containers falls into three categories (Garrett 1992):

- The gases that are required to control the atmosphere are carried with the container in either a liquid or solid form.
- Membrane technology is used to generate the gases by separation.
- The gases are generated in the container and recycled with pressure absorption technology and swing absorption technology.

The first method involves injecting nitrogen into the container to reduce the level of O_2 with often some enhancement of CO_2 (Anonymous 1987). It was claimed that such a system could carry certain cooled produce for 21 days compared with an earlier model, using nitrogen injection only, which could be used only on journeys not exceeding 1 week. The gases were carried in the compressed liquid form in steel cylinders at the front of the container, with access from the outside. O_2 levels were maintained by injection of nitrogen if the leakage into the container was greater than the utilisation of O_2 through respiration by the stored crop. If the respiration of the crop was high, the O_2 could be replenished by ventilation.

In containers, which use membrane technology, the CO_2 is generated by the respiration of the crop and nitrogen is injected to reduce the O_2 level. The nitrogen is produced by passing the air through fine porous tubes, made from polysulphones or polyamides, at a pressure of about 5–6 bar. These will divert most of the oxygen through the tube walls, leaving mainly nitrogen which is injected into the store (Sharples 1989).

A controlled atmosphere reefer container, which has controls that can give a more precise control over the gaseous atmosphere, was introduced in 1993. The containers use ventilation to control O_2 levels and a patented molecular sieve to control CO_2 . The molecular sieve will also absorb ethylene and has two distinct circuits that are switched at predetermined intervals so that while one circuit is absorbing, the other is being regenerated. The regeneration of the molecular sieve beds can be achieved when they are warmed to 100°C to drive off the CO_2 and ethylene. This system of regeneration is referred to as *temperature swing*, where the gases are absorbed at low temperature and released at high temperature. Regeneration can also be achieved by reducing the

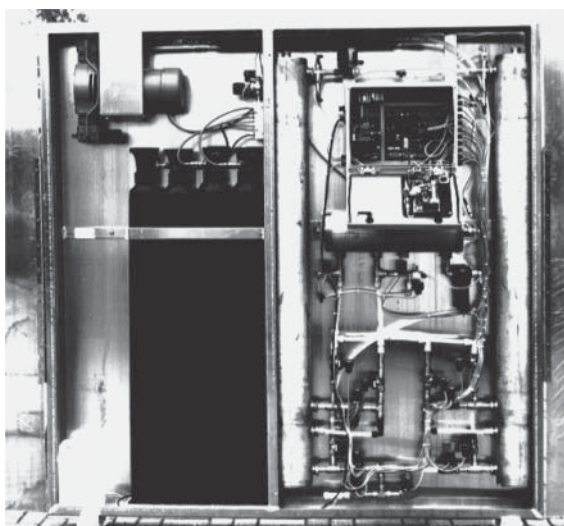


Figure 58 Control panel for CA container. (Source: T. Bach.)

pressure around the molecular sieve, which is called pressure swing. During the regeneration cycle, the trapped gases are usually ventilated to the outside, but they can be directed back into the container if this is required. The levels of gas, temperature and humidity within the container are all controlled by a computer which is an integral part of the container. It monitors the levels of oxygen from a paramagnetic analyser and the CO_2 from an infrared gas analyser and adjusts the levels to those which have been preset in the computer (Figure 58).

Lallu *et al.* (1997) described experiments on the transport of kiwi fruit in containers where the atmosphere was controlled by either nitrogen flushing or 'Purafil' to absorb ethylene or lime and 'Purafil'. The former maintained CO_2 levels of approximately 1% and O_2 at 2–2.5%, whereas in the latter, the CO_2 levels were 3–4% and O_2 levels increased steadily to 10%. A control container was included in the shipments, and on arrival, the ethylene levels in the three containers were less than $0.02 \mu\text{L L}^{-1}$.

Champion (1986) mentions the 'Tectrol' gas sealing specifications. Simulated commercial export of mangoes using the 'Transfresh' system of controlled atmosphere container technology was described in Ferrar (1988). Avocados and bananas were stored in two 'Freshtainer' controlled atmosphere containers, 40-feet long and controlled by microprocessors. The

set conditions for avocados were $7.4 \pm 0.5^\circ\text{C}$ for 8 days followed by $5.5 \pm 0.5^\circ\text{C}$ for 7 days, with $2 \pm 0.5\%$ O_2 and a maximum of $10 \pm 0.5\%$ CO_2 . Those for bananas were $12.7 \pm 0.5^\circ\text{C}$ for 8 days followed by $13.5 \pm 0.5^\circ\text{C}$ for 11 days, with $2.0 \pm 0.5\%$ O_2 and a maximum of $7 \pm 0.5\%$ CO_2 . Temperatures and container atmospheres were continually monitored and fruit quality was assessed after the predetermined storage period. The results confirmed that the containers were capable of very accurate control within the specified conditions. Also, the fruit quality was better than that for controls which were avocados held in a cold store for 2 weeks at 5.5°C in normal atmosphere and bananas held at $13.5 \pm 0.5^\circ\text{C}$ in an insulated container (Eksteen and Truter 1989).

Peacock (1988) described a controlled atmosphere transport experiment. Mango fruits were harvested from three commercial sites in Queensland when the content of TSS was judged to be 13–15%. Fruit were de-stalked in two of the three sources and washed, dipped for 5 min in $500 \mu\text{L L}^{-1}$ benomyl at 52°C , cooled and sprayed with prochloraz ($200 \mu\text{L L}^{-1}$), dried and sorted and finally size graded and packed in waxed fibreboard cartons. Some cartons contained polypropylene inserts, which cupped the fruits, other fruits were packed on an absorbent pad, but the majority was packed on expanded polystyrene netting. After packing, fruits were transported by road to a precooling room overnight (11°C). Pulp temperatures were $18\text{--}19^\circ\text{C}$ the following morning; after 36 h of transport to Brisbane and overnight holding in a conventional cool room, the fruits were placed in a controlled atmosphere shipping container. At loading, the pulp temperature was 12°C . Fruits were stored in the container at 13°C with 5% O_2 and 1% CO_2 for 18 days.

A UK company, Cronos Containers, supply inserts, called the Cronos Controlled Atmosphere System (manufactured under licence from B.O.C.), which can convert a standard reefer container to a controlled atmosphere container. The installation may be permanent or temporary and is self-contained taking some 3 h the first time. If the equipment has already been installed in a container and subsequently dismantles, then reinstallation can be achieved in about an hour. The complete units measure $2 \times 2 \times 0.2 \text{ m}$, which means that 50 of them can be fitted into a 40-foot dry container for transport. This facilitates management of the system. It also means that they

take up little of the cargo space when fitted into the container, only 0.8 m^3 . The unit operates alongside the container's refrigeration system and is capable of controlling, maintaining and recording the levels of O_2 , CO_2 and humidity to the levels and tolerances preset into a programmable controller. Ethylene can also be removed from the container by scrubbing. This level of control is greater than any comparable controlled atmosphere storage system, increasing shipping range and enhancing the quality of fresh fruit, vegetables, flowers, fish, meat, poultry and similar products. The system is easily attached to the container floor and bulkhead and takes power from the existing reefer equipment with minimal alteration to the reefer container. The design and manufacture is robust to allow operation in the marine environments that will be encountered in typical use. The system fits most modern reefers and is easy to install, set up, use and maintain. A menu-driven programmable controller provides the interface to the operator who simply has to preset the required percentages of each gas to levels appropriate for the product in transit. The controls are located on the front external wall of the container, and once set up, a display will indicate the measured levels of O_2 , CO_2 and relative humidity. The system consists of a rectangular aluminium mainframe onto which the various sub-components are mounted. The compressor is located at the top left of the mainframe and is driven by an integral electric motor supplied from the control box. Air is extracted from the container and pressurised (up to 4 bar) before passing through

the remainder of the system. A pressure relief valve is incorporated in the compressor along with inlet filters. Note also that a bleed supply of external air is ducted to the compressor and is taken via the manifold with a filter mounted external to the container. The compressed air is cooled before passing through the remainder of the system. A series of coils wound around the outside of the air cooler radiated heat back into the container. The compressed air then passes into this component which removes the pressure pulses produced by the compressor and provides a stable air supply. The water trap passing into the controlled atmosphere storage system then removes moisture. Water from this component is ducted into the water reservoir and used to increase the humidity when required. Two activated alumina drier beds are used in this equipment, each located beneath one of the nitrogen and CO_2 beds. Control valves are used to route the air through parts of the system as required by the conditioning process. Mesh filters are fitted to the outlet that vents nitrogen and CO_2 back into the container and to the outlet that vents oxygen to the exterior of the container. Nitrogen and CO_2 beds are located above the drier sieve beds and contain zeolite for the absorption of nitrogen and CO_2 .

Another type of reefer container that has controls that can give a more precise control over the gaseous atmosphere was introduced in 1993. The specifications are given in Table 35. The containers use ventilation to control oxygen levels and a patented molecular sieve to control CO_2 . The molecular sieve

Table 35 Specifications for a refrigerated controlled atmosphere container (source: adapted from Freshtainer INTAC 401)

	External dimensions	Internal dimensions	Door
Length	12,192 mm	11,400 mm	—
Width	2,438 mm	2,280 mm	2,262
Height	2,895 mm	2,562 mm	2,519
Capacity		66.6 m^3	
Tare		5,446 kg	
Maximum payload		24,554 kg	
Temperature range at 38°C ambient is -25 to $+29^\circ\text{C} \pm 0.2^\circ\text{C}$			
Oxygen down to 1% (+1 or -0.5%) up to 20 L h^{-1} removal			
Carbon dioxide 0–80% (+0.5 or -1%) up to 180 L h^{-1} removal			
Humidity 60–98% ($\pm 5\%$)			
Ethylene removal rate 120 L h^{-1} (11.25 mg h^{-1})			
Water recycled to maintain high humidity			

Table 36 Fruits given special entry permits by the Japanese Government (source: adapted from Kitagawa 1993)

Country	Fruit	Designated pest	Disinfestation method
Australia	Orange	Mediterranean fruit fly, Queensland fruit fly	Cold treatment (1 °C 16 days)
Australia	Lemon	Mediterranean fruit fly, Queensland fruit fly	Cold treatment (1 °C 14 days)
Canada	Cherry	Codling moth	Methyl bromide fumigation
Chile	Grape	Mediterranean fruit fly	Cold treatment (0 °C 12 days)
Israel	Orange	Mediterranean fruit fly	Cold treatment (1/2 °C 14 days)
Israel	Grapefruit	Mediterranean fruit fly	Cold treatment (1/2 °C 13 days)
Israel	Sweetie	Mediterranean fruit fly	Cold treatment (1 1/2 °C 16 days)
New Zealand	Cherry	Codling moth	Methyl bromide fumigation
New Zealand	Nectarine	Codling moth	Methyl bromide fumigation
New Zealand	Apple	Codling moth	Methyl bromide fumigation + cold treatment (1/2 °C 25 days)
Philippines	Mango – Carabao	Oriental fruit fly, Melon fly	Vapour heat treatment (46 °C, 10 min)
Spain	Lemon	Mediterranean fruit fly	Cold treatment (2 °C, 16 days)
South Africa	Orange	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
South Africa	Lemon	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
South Africa	Grapefruit	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
Swaziland	Orange	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
Swaziland	Lemon	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
Swaziland	Grapefruit	Mediterranean fruit fly	Cold treatment (–0.6 °C, 12 days)
Taiwan	Orange	Oriental fruit fly	Cold treatment (1 °C, 14 days)
Taiwan	Mango – Irwin, Haden	Oriental fruit fly, Melon fly	Vapour heat treatment (46.5 °C, 30 min)
Taiwan	Litchi	Oriental fruit fly	Vapour heat treatment (46.2 °C, 20 min) + cold treatment (2 °C, 42 h)
Thailand	Mango – Nang Klarngwun	Oriental fruit fly, melon fly	Vapour heat treatment (46.5 °C, 10 min)
Thailand	Mango – Nam Dorkmai, Pimsen dang, Rad	Oriental fruit fly, melon fly	Vapour heat treatment (47 °C, 20 min)
USA	Nectarine	Codling moth	Methyl bromide fumigation
USA	Walnut	Codling moth	Methyl bromide fumigation
Hawaii	Papaya – Solo	Mediterranean fruit fly or Melon fly	Vapour heat treatment (47.2 °C)
Washington	Cherry	Codling moth	Methyl bromide fumigation
Oregon	Cherry	Codling moth	Methyl bromide fumigation
California	Cherry	Codling moth	Methyl bromide fumigation

will also absorb ethylene and has two distinct circuits that are switched at predetermined intervals so that while one circuit is absorbing, the other is being regenerated. The regeneration of the molecular sieve beds can be achieved when they are warmed to 100 °C to drive off the carbon dioxide and ethylene. This system of regeneration is referred to as *temperature swing* where the gases are absorbed at low temperature and released at high temperature. Regeneration can also be achieved by reducing the pressure around the molecular sieve, which is called pressure swing. During the regeneration cycle, the trapped gases are usually ventilated to the outside, but they can be directed back into the container if this is required. The levels of gas, temperature and humidity within

the container are all controlled by a computer that is an integral part of the container. It monitors the levels of oxygen from a paramagnetic analyser and the carbon dioxide from an infrared gas analyser and adjusts the levels to those which have been preset in the computer.

Quarantine

Fruits that are susceptible to insect attack are allowed into Japan from certain specified countries, provided a specified disinfestation treatment is applied, for example see Table 36. For example, the Japanese market for Solo papaya from the United States was

opened for fruit in 1969 but only from the Hawaiian Islands. They were required to be treated with vapour heat treatment against Mediterranean fruit fly, Oriental fruit fly complex and melon fly.

There are a range of physical treatments, which can contribute further to pest management including heat treatments, biological control and controlled atmospheres. UV irradiation has been demonstrated to increase the natural resistance of some commodities and has been studied as a direct method for decay control. Radiation of fresh fruits and vegetables has been approved since 1989 at the 1 kGy dose and shows promise as an insect control treatment, but its benefits for decay control are limited.

Irradiation has been used postharvest on fruit and vegetables for many decades. It had become increasingly important as a quarantine treatment because of the phasing out of methyl bromide that was used to prevent the transfer of insect species between countries. Irradiation breaks the DNA bonds in insects, resulting in them being unable to develop, unable to reproduce or being killed depending on species and dose. Irradiation leaves no residues in the fruit or vegetable. Irradiation doses that are needed to kill the insect may be higher than those tolerated by fruits, and therefore, the other unique feature of irradiation

treatments is that they are generally designed to sterilise insects, not to kill them. In the case of fruit flies, APHIS (2002) has established the criterion for a successful dose as the non-emergence of adults to prevent sterile adults from triggering control strategies if detected in traps within areas free of established fruit fly populations. The USDA approved the use of irradiation to treat fruit for importation into the United States in 2002 (APHIS 2002). According to the USDA Fresh Fruits and Vegetables Import Manual, irradiation as an optional treatment is available only after an exporting country has entered into a framework equivalency work plan agreement and met other specified requirements. The facility used for irradiation must be certified by the national nuclear regulatory authority of the country where the facility is located before involvement with USDA. This can represent challenges related to the location of the facility to the production sites. APHIS of the USDA in 'Irradiation treatment of imported plant pests, Part 305.2' Authority: 7 U.S.C. 7701-7772; 21 U.S.C. 136 and 136a; 7 CFR 2.22, 2.80, and 371.3. supplied comprehensive regulations related to quarantine for importing in fresh fruit and vegetables (Table 37). The New Zealand Ministry of Agriculture and Forestry

Table 37 Irradiation for certain plant pests in imported regulated articles into the United States (source: reproduced with permission from the Legal Information Institute, Cornell University Law School)

Scientific name	Common name	Dose (Gy)
<i>Anastrepha ludens</i>	Mexican fruit fly	70
<i>Anastrepha obliqua</i>	West Indian fruit fly	70
<i>Anastrepha serpentina</i>	Sapote fruit fly	100
<i>Anastrepha suspensa</i>	Caribbean fruit fly	70
<i>Bactrocera jarvisi</i>	Jarvis fruit fly	100
<i>Bactrocera tryoni</i>	Queensland fruit fly	100
<i>Brevipalpus chilensis</i>	False red spider mite	300
<i>Conotrachelus nenuphar</i>	Plum curculio	92
<i>Crotophlebia ombrodelta</i>	Litchi fruit moth	250
<i>Cryptophlebia illepidia</i>	Koa seedworm	250
<i>Cylas formicarius elegantulus</i>	Sweetpotato weevil	150
<i>Cydia pomonella</i>	Codling moth	200
<i>Euscepes postfasciatus</i>	West Indian sweetpotato weevil	150
<i>Grapholita molesta</i>	Oriental fruit moth	200
<i>Omphisa anastomosalis</i>	Sweetpotato vine borer	150
<i>Rhagoletis pomonella</i>	Apple maggot	60
<i>Sternonchetus mangiferae</i> (Fabricus)	Mango seed weevil	300
Fruit flies of the family Tephritidae not listed above		150
Plant pests of the class Insecta not listed above, except pupae and adults of the order Lepidoptera		400

approved access to the New Zealand market for Australian mangoes in 2004, papaya in 2006 and litchi in 2008. Irradiation is the approved treatment for insects of concern to New Zealand, and the minimum dose required by New Zealand for the insect pests is 250 Gy. Irradiation has been used for purposes other insect control. Mansour and Mohamad (2004) tested irradiation on the control of codling moth (*Cydia pomonella*) and found that the radio sensitivity of codling moth eggs decreased with increasing age. However, a dose of 60 Gy completely prevented adult emergence, and at 100 Gy, all larvae died before pupation.

Considerable work has been done on the effects of irradiation on the quality of the fruit. The effect of γ irradiation at 0.3, 0.6 or 1.0 kGy on ripening of Klui Khai bananas was investigated. During subsequent storage at room temperature of approximately 30 °C, irradiated fruit lost weight, became softer and ripened more quickly than non-irradiated fruit (Chanloy *et al.* 2005). Fenfen Kang *et al.* (2012) found that X-ray irradiation at 0.2 and 0.4 kGy could reduce the respiration rate of grapes and extended their shelf life. They found that there were no significant other physical or chemical effects of irradiation, and the irradiation fruit had a better appearance than the non-irradiation fruit after 14 days storage at 1.5 ± 0.5 °C and $75 \pm 5\%$ r.h.

In order to prevent the transmission of crop pests and diseases between countries, safeguards and

restrictions are placed on the international movement of fresh produce. National laws may prevent the import of fresh produce from designated areas or require that they be treated in such a way as to eliminate certain pests or diseases.

Since the establishment of the single market in the European Community in January 1993, health requirements for plant material entering the Community have been harmonised. The general rule is that all plant material intended for planting from third countries (countries outside the EC) except seeds and aquarium plants need a phytosanitary certificate. In addition, a certificate is required for certain fruit entering the EU (Table 38), but these are constantly being revised and the local EU office should be consulted before shipments are made.

In the EC, general requirements are that a phytosanitary certificate must accompany fruit and vegetable in order to be permitted to entry from non-EC countries (Table 39). In broad terms, this includes all major fruit, other than bananas and grapes, some leafy vegetables and potatoes from a limited number of countries. A phytosanitary certificate is essentially a statement that the plants or plant produce or products to which it relates have been officially inspected in the country of origin or country of despatch, comply with statutory requirements for entry into the EC, are free from certain serious pests and diseases, and are substantially free from other harmful organisms.

Table 38 Fruit that require a phytosanitary certificate to enter the European Union in 1993 (source: Defra 2006)

Scientific name	Common name	Origin
<i>Anona</i>	Custard apple	Third countries
<i>Citrus</i> and hybrids	Orange, lemon, lime, etc.	Third countries
<i>Cydonia</i> Mill	Quince	Non-European countries
<i>Diospyros</i>	Persimmon, date plum	Non-European countries
<i>Fortunella</i> and hybrids	Kumquat	Third countries
<i>Malus</i>	Apple	Non-European countries
<i>Mangifera</i>	Mango	Non-European countries
<i>Passiflora</i>	Passion fruit	Non-European countries
<i>Poncirus</i> and hybrids	Ornamental citrus	Third countries
<i>Psidium</i>	Guava	Non-European countries
<i>Pyrus</i>	Pear	Non-European countries
<i>Ribes</i>	Gooseberry, redcurrant, blackcurrant	Non-European countries
<i>Rubus</i>	Blackberry, raspberry, dewberry, loganberry	Third countries
<i>Syzygium</i>	Clove, jambolan, rose apple	Non-European countries
<i>Vaccinium</i>	Cranberry, blueberry	Non-European countries
<i>Zea mays</i>	Maize (seeds)	Third countries

Table 39 Phytosanitary requirements for fruit imported into the EC. Fruit of *Fortunella*, *Poncirus*, *Citrus* spp. and hybrids must be free from leaves and peduncles. (source: Defra 2006)

Botanical name	Common name	Origin	Requirement
<i>Annona</i>	Custard apple	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Citrus</i> and hybrids	Orange, lemon, lime, etc.	All non-EC countries	Phytosanitary certificate
<i>Cydonia</i>	Quince	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Diospyros</i>	Persimmon, date plum	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Fortunella</i> and hybrids	Kumquat	All non-EC countries	Phytosanitary certificate
<i>Malus</i>	Apple	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Mangifera</i>	Mango	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Momordica</i>	Bitter melon	All non-EC countries	Phytosanitary certificate
<i>Passiflora</i>	Passion fruit	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Poncirus</i> and hybrids	Ornamental citrus	All non-EC countries	Phytosanitary certificate
<i>Prunus</i>	Includes cherry, plum, peach, apricot	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Psidium</i>	Guava	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Pyrus</i>	Pear	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Ribes</i>	Gooseberry, blackcurrant, redcurrant	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Solanum melongena</i>	Aubergine, egg plant	All non-EC countries	Phytosanitary certificate
<i>Syzygium</i>	Jambolan and rose apple	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
<i>Vaccinium</i>	Cranberry, blueberry	Non-European countries	Phytosanitary certificate
		Non-EC European countries	None
All other fruit		All non-EC countries	Phytosanitary certificate

Chemical pesticide residues in fruits and vegetables are restricted and controlled by legislation. The work of DG VI (Agriculture) of the EC has the responsibility of harmonising chemical pesticide residues in food. With the introduction of Single Market on 1 January 1993, a first list of 55 chemicals was produced which contained their maximum residue level (MRL). The European Union provides directives for MRL and these are communicated in directives issued in the Official Journal of the European Communities. For example, Council Directive 93/58/EEC of 29 June 1993.

In 2008, the Japan inspection services inspected 287,244 kg of mangoes from the United States and rejected only 1 kg, and 926,530 kg of papaya were imported of which 21 kg were rejected. For Table

grapes, 1,923,643 kg were imported from the United States and 282 kg were rejected and 101,483 kg were fumigated on entry to Japan.

In the United States, the Animal Plant Health Inspection Service developed the FAVIR (fruits and vegetables import requirement) database in July 2007 known as Quarantine 56. This established a streamlined approach for the importation of certain fruits and vegetables without specific prior rule making. The database allows customers to search for authorised fruits and vegetables by commodity or country and determine the general requirements for their importation into the United States. This database can be accessed online at: http://www.aphis.usda.gov/import_export/plants/plant_imports/quarantine_56/favir.shtml.



Figure 59 Metal container used for airfreight of fresh produce. Note the boxes are badly stacked as the bottom six layers are stacked on their sides and boxes are designed to be stacked upright to protect the produce inside.

International transport by airfreight

International transport of fresh fruits and vegetables is constantly being questioned in the news media, especially in relation to airfreight transport. This is mainly in terms of the high environmental costs of using fossil fuels for aeroplanes to provide consumers with crops all the year round, which in the past were seasonal. Most of this export trade is from less developed countries to industrialised countries and can be a major source of income for producing countries. This is a very involved subject and not one for a technical work such as this.

For export, fruit and vegetables are usually packed into cartons which in turn are packed into closed

containers, igloos or net covered pallets that are specially designed to fit into a specific type of aircraft. The pallets or containers are loaded with the produce and then taken to the aircraft for loading to speed the process. Containers come in various shapes and sizes (Figures 59 and 60), which are designed to maximize the use of the interior of the aircraft.

Akinaga and Kohda (1993) measured the conditions that airfreight cargo was exposed to during transport. They showed that most aircraft have pressurised cargo compartments that are maintained at low humidity (20–40% r.h.) and the same temperature as the passenger compartment. Okras loaded into a freight container without precooling showed a progressive decrease in temperature and increase in humidity during the flight. The increase in humidity inside the container was considered to be due to the poor ventilation characteristics of the container. In another shipment observed by Akinaga and Kohda (1993), the carbon dioxide and ethylene concentration inside a unit load device lined with PVC film for waterproofing containing chrysanthemum flowers was shown to increase. However, the maximum level of CO_2 was only about 0.5% and ethylene at $0.23 \mu\text{L L}^{-1}$ and was unlikely to have any effect on the flowers.

Containers that are used on aircraft can have facilities that provide some control over temperature and gases. Reid (2001) recommended a cold chain including refrigerated air containers to reduce losses that occur during shipping and handling of cut flowers. One company which produces and has patented such equipment is Envirotainer Worldwide from the

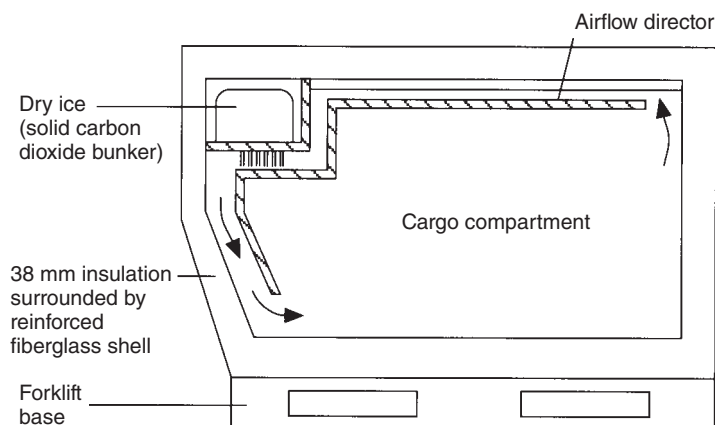


Figure 60 Diagram of a vertical section through a controlled atmosphere airfreight container.

Table 40 Controlled atmosphere containers used for airfreight (source: adapted from Envirotainer Worldwide)

Type	Internal capacity (m ²)	Tare weight (kg)	Maximum gross weight (kg)	Dry ice capacity (kg)
LD3	3.5	190	1,591	56
LD7/9	8.6	499	6,033	56
LD5/11	6.0	408	3,175	90

United States (Sinco 1985). They produce three sizes of insulated containers which are cooled by a fan circulating air across dry ice (solid CO₂) and then through the product in the container. The container has up to 57 kg of dry ice in a compartment that is separated from the cargo compartment. There are no moving parts in the container and air circulation is by convection. Temperature in the cargo compartment is regulated by airflow controls. The sizes are given in Table 40.

Sinclair (1988) reported that Lufthansa had the LD3 airfreight container with a pay load of 1350 kg and LD7 with a payload of 4755 kg. They are insulated with Alu-foam panels affixed to a pallet and air is passed over the dry ice by means of a battery-operated fan which can maintain the temperature within the container at the selected range for the entire transport time.

Air cargo is charged by weight. However, if the volume is greater than 366 cubic inches per kilogram (6 L kg⁻¹), a formula may be applied by the airline to increase the basic charge. The transport cost is a major item in marketing of fresh produce. Examples of costs for beans and cut flowers exported from Kenya to United Kingdom and Holland, respectively, were given by Jaffee (1993) (Table 41) and for limes

Table 41 Distribution of sales revenue, expressed as a percentage of the total, between Kenya and United Kingdom for French beans in April 1985 and Kenya and Holland for cut flowers (source: adapted from Jaffee 1993)

	Fresh French beans (%)	Cut flowers (%)
F.O.B. Kenya	25.6	19.2
Freight and handling	21.3	12.8
Importer's costs and profits	12.7	6.4
Wholesaler's costs and profits	10.4	10.6
Retailer's costs and profits	30.0	50.0

Table 42 Costs and returns (in £ sterling) for an airfreight shipment of limes based on one carton containing 153 fruits weighing 4.13 kg (source: adapted from Thompson *et al.* 1974)

	Expense	Total
Purchase of fruit	£0.38	—
Carton	£0.12	—
Airfreight from Khartoum to London	£0.84	—
Customs and agents charges	£0.45	—
Total expenditure (excluding labour)	—	£1.79
Receipts	—	£2.69

from Sudan to United Kingdom by Thompson *et al.* (1974) (Table 42). The limes used in the Sudan were the local cultivar which is called Baladi. It had a good strong flavour but was generally smaller than the market requirement, which was greater than 42 mm diameter. In studies, it was found that the distribution of fruit sizes in a commercial harvest was:

- >42 mm diameter: 7.5% with a mean weight of 43.8 g
- 38–42 mm diameter: 25.2% with a mean weight of 33.7 g
- <38 mm diameter: 67.3% with a mean weight of 22.6 g.

Airfreight charges are normally considerably higher than sea freight (Table 43).

Table 43 Comparison of the variable costs of transporting avocados or mangoes from the Kenyan highlands to Germany either by airfreight or by 20-foot reefer container by sea freight

	Airfreight 2 tonnes	Sea freight 9 tonnes
Transport: field to packhouse	9	41
Transport: packhouse to airport	7	—
Transport: packhouse to seaport	—	260
Stowing in container	—	33
Export clearance at airport	500	—
Export clearance at seaport	—	33
Handling at seaport	—	24
Export fees	13	59
Airfreight	1374	—
Sea freight	—	3000
Total	1903	3417
Costs c.i.f. per kilogram	\$0.95	\$0.38

All figures have been converted to US\$ and the study was made in June 1986.

Temperature monitoring

Monitoring the storage conditions of the crop during transport is very important. Reefer containers are fitted with chart recorders that monitor the temperature on the air before and after it passes over the cooling coils. In modern containers, an integral computer often carries out this function. In addition, portable recorders are often placed in the boxes of produce in order to monitor the actual condition close to the produce. These are often contained in sealed units, which are sometimes used as evidence where there is a dispute as to the temperature the crop has been exposed to. Several companies make these recorders, perhaps the best known is Ryan Instruments Incorporated.

The recorders have a temperature sensor based on a bimetallic strip attached to a pressure sensitive roll of paper which passes below a pointer attached to the bimetallic strip and records a trace of the temperature over time. A British company called Green PC developed a smaller device (about 55 mm long $\times$ 30 mm diameter) called Tiny Talk. The temperature is monitored and recorded on a chip and can be downloaded onto a computer to give a graph of the temperature over time (Robinson 1993). This type of design of recorder has now completely replaced Ryan recorders. They have become reasonably cheap and flexible with the provision of downloading the data onto a computer.

11

Fruit ripening

Fruits can be classified into two groups, climacteric and non-climacteric. The former can be defined as fruit that can be ripened after harvest and the latter can be defined as fruit that do not ripen after harvest. The term *climacteric* was first applied to fruit ripening in the mid 1920s by Kidd and West (1927). They observed an increase in the respiration rate as measured by the production of CO₂ by Bramley's Seedling apples around the time of the normal commercial harvest. Biale and Barcus (1970) published measurements of the respiration rate of some selected fruit and classified them into climacteric, non-climacteric and indeterminate on the basis of their respiration rate. For example, they classified banana, biriba, breadfruit, mango, papaya and soursop as climacteric; cacao, cashew and guava as non-climacteric and jackfruit, jambo, passion fruit and sapote as indeterminate. Other fruits that have been shown to display typical climacteric respiration patterns include annonas, apricot, avocado, blueberry, cantaloupe melon, durian, feijoa, kiwifruit, peach, persimmon, plum, pome fruits and watermelon. Other fruits that can be classified as non-climacteric includes aubergine, blackberry, capsicum, cherry, citrus fruits, cucumber, grape, litchi, olive, pineapple, pomegranate, raspberry, strawberry and tamarillo. In some cases, there is conflict of opinion on classification. For example, fig and melon were classified as climacteric by Wills *et al.* (1989), but Biale (1960) classified them both as

non-climacteric and Pratt (1971) showed that both Honeydew muskmelon and PMR-45 cantaloupes were climacteric. Biale and Barcus (1970) classified passion fruit as indeterminate, whereas Akamine *et al.* (1957) classified them as climacteric. Grierson (1993), commenting on the classification of fruits into climacteric and non-climacteric, reported that parts of citrus fruits are climacteric and other parts of the same fruit are non-climacteric.

Respiration rate of vegetables and non-climacteric fruit tends to progressively reduce during development of the plant. Wills (1998) found that in experiments with strawberries, oranges, lettuces, beans, Chinese cabbage, bak choi (*Brassica chinensis*), choi sum (*B. parachinensis*) and gai lan (*B. alboglabra*) exposed to air containing 10–0.005 µL L⁻¹ ethylene at either 0–2.5 or 20 °C, the storage life of all produce was found to be linearly extended with a logarithmic reduction in ethylene concentration across the whole concentration range. The ethylene level found to accumulate around produce in markets was in the range 0.06–1.45 µL L⁻¹, suggesting that premature ageing occurred in all non-climacteric crops during normal marketing. There appears to be no benign level of ethylene so that any reduction of ethylene concentration should help in maintaining quality of vegetables and non-climacteric fruits. In non-climacteric fruit such as strawberry, there was little change in ethylene production during ripening (Manning 1993). However, he showed that auxin

produced by the achenes could affect the colour (anthocyanin production) of the maturing fruit. Removal of the achenes from developing strawberry fruit resulted in quicker colouring of the area where they were removed.

Climacteric fruits are often harvested in an immature state and ripened postharvest. Most climacteric fruit species will ripen normally on the tree after they have reached full maturity. However, in the case of avocado, which is a climacteric fruit, they do not normally ripen until they are harvested and can remain in a mature but unripe condition on the tree until harvested.

Ripening involves a number of physical and chemical changes that occur in fruit. These normally occur when the fruit has developed to what is referred to as *full maturity*. However, immature fruit may be harvested and exposed to certain postharvest conditions (temperature, gas content in the atmosphere and humidity) that are conducive to ripening. The changes that can occur during ripening may be independent of each other. But under the correct circumstances, these processes are initiated together and proceed together producing an acceptably ripe fruit. In other circumstances, changes such as reduction in acidity or change in colour may occur at a different rate to other processes producing a fruit that is fully ripe in all other aspects except that one.

Initiation of ripening occurs when a threshold level of ethylene is reached in the cells of the fruit. This occurs naturally within the fruit at a point during maturation. It can occur earlier if the fruit undergoes stress, for example if a disease-causing microorganism attacks the fruit or the tree it is growing on. Postharvest ripening can also be initiated by exposing the fruit to exogenous ethylene so that the threshold level infiltrates into the cells of the fruit. As fruits approach maturity, they become more sensitive to exogenous ethylene-initiated ripening (Knee *et al.* 1987). Duque and Arrabaca (1999) found that the respiratory climacteric and the induction of alternative oxidase were tightly and temporally linked. The metabolic pathway within the cells of the plant that result in ethylene production is complex. Ethylene biosynthesis involves a series of steps culminating in the synthesis of SAM (S-adenosyl-methionine) from the amino acid methionine. SAM is converted to ACC (1-aminocyclopropane-1-carboxylic acid) by the action of the enzyme ACC synthase. ACC is

the immediate precursor of ethylene biosynthesis in plants. ACC oxidase is the enzyme required to convert ACC to ethylene (Hamilton *et al.* 1990). ACC oxidase is a labile enzyme and is sensitive to O₂. The biosynthesis of ethylene in ripening fruit was shown in early work by Gane (1934) to cease in the absence of O₂. Its biosynthesis also can be inhibited at temperatures above 35 °C. In terms of ethylene action, it was suggested that high levels of CO₂ in stores could compete with ethylene for binding sites in fruits (Burg and Burg 1967). They also showed that in the presence of 10% CO₂, the biological activity of 1% ethylene was abolished. Yang (1985) also showed that CO₂ accumulation in the intercellular spaces of fruit acts as an ethylene antagonist.

Changes during fruit ripening

Colour

The most obvious change in many fruits during ripening is their external colour. In tomatoes, chlorophyll levels are progressively broken down into phytyl. It was observed that in cherry tomatoes, the total chlorophyll level was reduced from 5490 µ 100 g⁻¹ fresh weight in green fruit to 119 µ 100 g⁻¹ fresh weight in dark red fruit (Laval Martin *et al.* 1975). Concurrent with this degradation process, lycopene, carotenes and xanthophylls are synthesised giving the fruit its characteristic colour usually red (Grierson and Kader 1986). Total carotenoids in cherry tomatoes increased from 3297 µ 100 g⁻¹ fresh weight in green fruit to 11,694 µ 100 g⁻¹ fresh weight in dark red fruit (Laval Martin *et al.* 1975). This colour development occurs in both the pulp and the flesh of the tomato. The optimum temperature for colour development was given as 24 °C, whereas at 30 °C and above, lycopene is not formed.

The pigments in the peel of bananas and plantains are chlorophylls and carotenoids. The change in colour of ripening fruits is associated with the breakdown of chlorophylls with carotenoid levels remaining relatively constant (Seymour 1985, Montenegro 1988) (Figure 61). Cavendish banana cultivars can fail to completely degreen when they are ripened at 25 °C and above (Seymour *et al.* 1987a, 1987b, Semple and Thompson 1988). This can result in bananas, which are ripe in every other respect, remaining green. The higher the temperature, the more obvious the

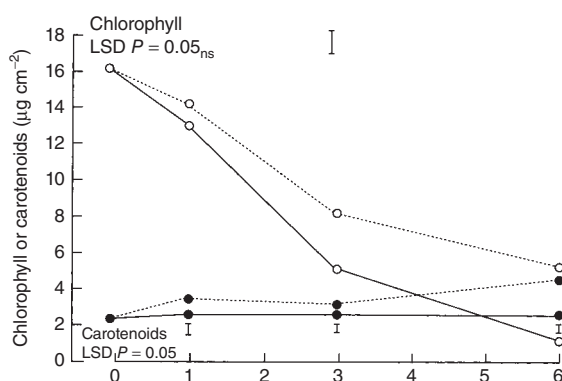


Figure 61 Changes in the pigment level of bananas during ripening at either 20 or 35 °C. The fruit were exposed to 1000 μL^{-1} before being ripened in air. (Source: Seymour 1985.)

effect. It is one cause of the physiological disorder of Cavendish bananas called pulpa crema or yellow pulp. This is where banana fruit are initiated to ripen on the plant, but because the ambient temperature is above 25 °C, the pulp ripens but the chlorophyll in the skin is not fully broken down. With plantains, it was shown that complete chlorophyll destruction can occur even at 35 °C (Seymour 1985, Seymour *et al.* 1987a, 1987b). Studies on why this effect of temperature on degreening of Cavendish bananas occurs failed to reach a definitive conclusion, although there was some indication that it was related to the thylakoid ultrastructure of the chloroplasts (Seymour 1985, Blackbourn *et al.* 1990).

Colour changes during ripening of many fruit, including bananas, have been used as a rough guide to the stage of ripeness in many banana cultivars. It is commonly used commercially in the form of colour matching charts based on the degree of peel yellowing where colour index 1 is allocated to fruit that are dark green and colour index 6 is for fruit that are fully yellow (Von Loesecke 1950, Lizada *et al.* 1990). Examples of these colour charts are supplied by commercial banana companies and can also be found in Stover and Simmonds (1987), Abdullah and Pantastico (1990) and Thompson (1996). Standard colour charts exist for a variety of fruits, for example tomatoes (Figure 3).

Advanced stages of banana ripeness are characterised by the appearance of brown flecks or spots on the skin. Conflicting reports, however, dispute the colour index at which these superficial spots

appear. For triploid bananas of the same cultivar, Miem (1980) reported colour index 5.5, whereas Ng and Mendoza (1980) showed that they occur at colour index 3.5–4.

Texture

Fruits normally soften progressively during ripening (Figure 62). Instrumental measurement of fruit texture needs careful application and interpretation to ensure they are relevant to organoleptic perception of texture (Batu and Thompson 1993). Although exact biochemical mechanisms have not yet been fully established, it is believed that softening is at least partly due to the breakdown of starch and other non-pectic polysaccharides in the pulp, thereby reducing cellular rigidity (Lizada *et al.* 1990). Softening of bananas during ripening appears to be associated with two or three processes (Smith 1989). The first of these is the breakdown of starch to form sugars as starch granules could have a structural function in the cells. The second is the breakdown of the cell walls due to the solubilisation of pectic substances and even the breakdown of cellulose. Smith (1989) found evidence of increased activity of cellulase during banana ripening. The possible third is the movement of water from the peel of the banana to its pulp during ripening. This latter process could affect the turgidity of the skin that would be enhanced by transpiration losses. This change in the moisture status of the fruit also contributes to the ease at which the peel can be detached from the pulp. As bananas and plantains ripen, the ratio of the mass of the pulp to the mass of the peel increases and the peel becomes progressively easier to detach from the pulp. This pulp to peel ratio can be a measure of the fruit's ripeness. In studies of Japanese pears, Sirisomboon *et al.* (2000) found that the skin contributed 70–80% of the firmness of the fruit.

During ripening, there are major changes in the pectic polymers in the cell walls (Tucker and Grierson 1987). Neutral sugars, mainly galactose in most fruit but also arabinose, are major components of the cell wall neutral pectins are lost. There are also losses of acidic pectin. The solubility of these polyuronides increases, and in several cases, they have been shown to be progressively depolymerised (Tucker and Grierson 1987). Sirisomboon *et al.* (2000) also found that the solubilisation of non-soluble pectin

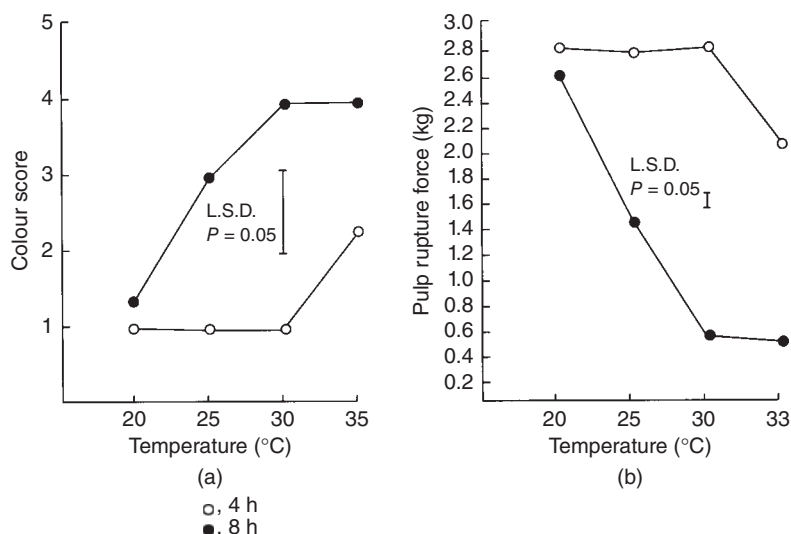


Figure 62 (a,b) The effects of exposure at 20 °C for either 4 or 8 h to 1 ml L⁻¹ of acetylene at various temperature on the ripeness of bananas after 6 days. (Source: Smith *et al.* 1986. Reproduced with permission of John Wiley & Sons Ltd.)

to water-soluble pectin appeared to influence the texture of Japanese pears.

Stow and Genge (1993) measured cell wall strength of apples using osmotic techniques. They found that cell walls did not weaken during fruit softening and suggested that softening results from loss of cell-to-cell cohesion. Soluble pectin content of apples did not correlate with fruit firmness, which casts doubt on the hypothesis that softening results from loss of pectin from the middle lamella of cells (Stow and Genge 1993). The major effect of ethylene removal from stored apples is a delay in the onset of softening (Dover and Stow 1993). They also suggested that removal of ethylene from the store could slow softening once it has started. Cellulase is involved in fruit softening during ripening of avocado fruits and at least 11 multiple forms were identified (Kanellis and Kalaitzis 1992).

Genetic engineering has produced fruit that do not soften normally, but due to restrictions on products of biotechnology in the EU and other countries, the market was restricted.

Carbohydrates

During the developmental stage of climacteric fruit, there is a general increase in starch content. The most striking chemical change during ripening is the

hydrolysis of starch to simple sugars. Starch occurs in the plastids of unripe avocados at levels of about 12 mg g⁻¹ on a dry weight basis, but this was shown to reduce to undetectable levels in ripe fruit (Pesis *et al.* 1976). In Kiwifruit, starch was shown to be hydrolysed to glucose and fructose and to a lesser degree to sucrose during ripening (Okuse and Ryugo 1981). Medlicott and Thompson (1985) and Medlicott *et al.* (1987a, 1987b, 1987c) showed that during ripening of mangoes, the starch content was completely hydrolysed to sugar during ripening. The major sugars were identified as glucose, fructose and sucrose, with the latter being in the largest quantities (Figure 63). The reduction in the level of sucrose towards the end of the storage period was probably due to it being used by the fruit for metabolic activity after all the starch had been hydrolysed. In dessert bananas, ripening involves a reduction in starch content from around 15–25% to less than 5% in the ripe pulp, coupled with a rise of similar magnitude in total sugars (Lizada *et al.* 1990, Desai and Deshpande 1975, Barnell 1943). During the early part of ripening, sucrose is the predominant sugar, but in the later stage, glucose and fructose predominate (Barnell 1943).

The proportion of the different sugars is related to the stage in the respiratory climacteric of the fruit (Hubbard *et al.* 1990). They also show that

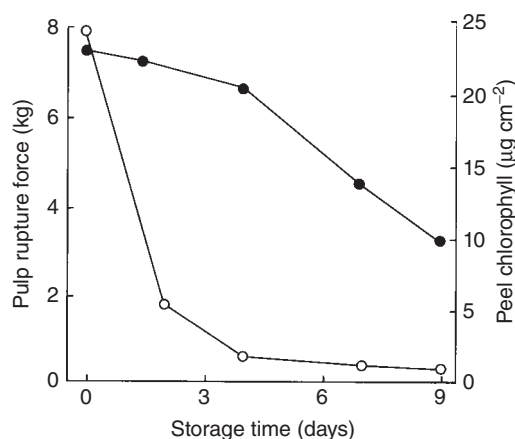


Figure 63 Changes in the peel chlorophyll content and pulp firmness of Keitt mangoes during storage at 22 °C. (Source: Medicott and Thompson 1985. Reproduced with permission of John Wiley & Sons Ltd.)

starch is broken down to sucrose by the action of sucrose phosphate synthetase and non-reducing sugars from sucrose by acid hydrolysis. The onset of the starch-sugar conversion has been shown to be influenced by harvest maturity, with more mature fruits responding earlier. These changes have been demonstrated in both triploid (*Musa AAA*) (Madamba *et al.* 1977) and diploid (*Musa AA*) (Montenegro 1988) bananas. In bananas, the breakdown of starch is usually completed during ripening, but in plantains, this breakdown is not complete even when the fruit is fully yellow and soft (George 1981). In Apple bananas (*Musa AA*), the fruit still has residual starch when it is fully yellow and need to be ripened further before being eaten (Wei and Thompson 1993).

In non-climacteric fruit, sugars rather than starch is synthesised during development and maturation. For example, grapes have high levels of sugar with glucose being the predominant sugar in unripe grapes, where it can account for 85% of the total sugar, whereas in ripe fruit, fructose usually slightly exceeds glucose (Burton 1982).

Acids

Although the development of sweetness is important, organic acids also influence the overall fruit flavour. Acids help form the desirable sugar to acid balance necessary for a pleasant taste. Acidity of fruits generally decreases during ripening. Organic acids present

in fruit vary with different fruit, with malate and citrate being the most common (Ulrich 1970, Ali Azizan 1988, quoted by Abdullah and Pantastico 1990).

Bananas and plantains like most other fruits are acid with a pulp pH below 4.5 (Von Loesecke 1950). Palmer (1971) showed that the main acids in bananas were citric, malic and oxalic and the levels of these acids normally increase during ripening. Malic is the major organic acid in apples and pears but some apples contain quantities of citric and some pears quantities of quinic (Ulrich 1970). TA in bananas increased during ripening at 20 °C and then decreased (Desai and Deshpande 1975), for Dwarf Cavendish, it was 1.95 meq. 100 g⁻¹ fresh weight at harvest and reached a peak at 5.15. Medicott and Thompson (1985) showed that in Keitt mangoes, the principal acids were citric and malic and that there was a large decrease in citric acid during ripening, but only a small decrease in malic (Figure 64). Ascorbic acid content increased during ripening at 20 °C for 21 days and then decreased slightly to the end of the experiment which was after 7 weeks storage (Desai and Deshpande 1975). For Dwarf Cavendish bananas, ascorbic acid was 0.25 mg 100⁻¹ fresh weight of the pulp at harvest rising to 3.11 mg 100⁻¹ after 3 weeks at 20 °C and for Rasabale, it was 5.10 mg 100⁻¹ at harvest and 12.45 mg 100⁻¹ after 3 weeks storage at 20 °C.

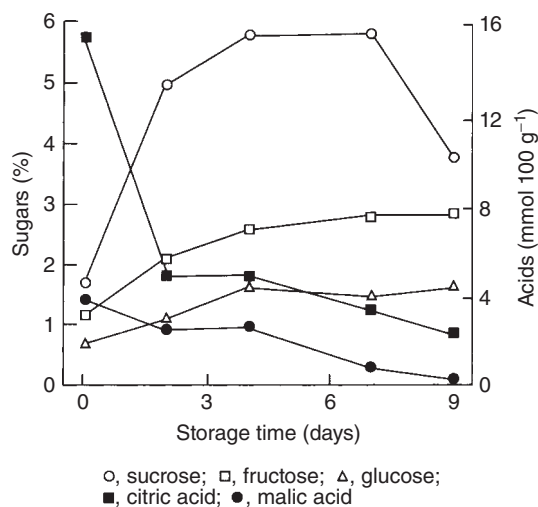


Figure 64 Changes in the sugar and acid contents of Keitt mangoes during storage at 22 °C. (Source: Medicott and Thompson 1985. Reproduced with permission of John Wiley & Sons Ltd.)

Phenolic compounds

Bananas and plantain fruits can contain high levels of phenolic compounds especially in the peel (Von Loesecke 1950). Phenolics, such as tannins, are polymerised to insoluble compounds resulting in a reduction of astringency in the ripe banana fruit (Lizada *et al.* 1990). Tannins are perhaps the most important phenolic from the point of view of fruit utilisation because they can give fruit an astringent taste. As fruit ripens, their astringency becomes lower, which seems to be associated with a change in structure of the tannins, rather than a reduction in their levels, in that they form polymers (Von Loesecke 1950, Palmer 1971). Phenolics are common in many fruits and are responsible for the oxidative browning reaction when the pulp of fruit is cut, especially if they are immature. The enzyme polyphenoloxidase is responsible for this reaction (Palmer 1971). In Carabao mango fruit, there was a progressive loss in total phenolic content during ripening, which was associated with loss in astringency (Tirtosoekotjo 1984). Levels of polyphenols, particularly the high molecular weight polyphenols, in guava were shown to decrease as the fruit matured (Ito *et al.* 1987). Young guava fruit contained 620 mg 100 g⁻¹ fresh weight, of which 65% were condensed tannins. In persimmon, the soluble tannin content in fruit varied between cultivars, and in astringent cultivars, it was particularly high in immature fruit (Ito *et al.* 1987).

The latex, which spurts from the broken pedicel of immature mango fruits (Figure 65), is structurally similar to phenolic allergens found in other genera of Anacardiaceae. The main component of mango latex was identified as 5-[2(Z)-heptadecenyl] resorcinol (Bandyopadhyay *et al.* 1985).



Figure 65 Mango latex spurting from the broken pedicel of a freshly harvested fruit.

Flavour and aroma

Flavour is the subtle and complex perception combining taste, smell and texture or mouth feel. Ripening usually brings about an increase in simple sugars to give sweetness, a decrease in organic acids and phenolics to reduce bitterness and minimise astringency and an increase in volatiles to produce the characteristic flavour. The characteristic aroma of ripe fruit is due to the production of a complex mixture of individual volatile components. In apples and pears, butyl ethanoate, 2-methyl butyl ethanoate and hexyl ethanoate are typical flavour and aroma compounds that are synthesised during ripening. Terpenoid compounds such as linalool and its epoxide and farnesene have been shown to develop in some apple cultivars (Dimick and Hoskins 1983). Controlled atmosphere storage of apples in either 2% O₂ and 98% N₂ or 2% O₂, 5% CO₂ and 93% N₂ showed that few organic volatile compounds were produced during the storage period (Hatfield and Patterson 1974). Even when the fruit were removed from storage, they did not synthesise normal amounts of esters during ripening.

At least 350 flavour and aroma compounds have been shown to occur in ripe bananas, and their synthesis generally occurs relatively late in the climacteric, with acetate and butyrate esters accounting for about 70% of the total volatile emanations (Tressl and Drawert 1973). McCarthy *et al.* (1963) claimed that amyl esters and butyl esters gave bananas their distinctive flavour and aroma and a fruity flavour and aroma, respectively. The exact relationship between the chemistry and the flavour and aroma of bananas has not yet been fully determined. However, besides the volatile compounds above, other esters, as well as aldehydes, alcohols and ketones, have been associated with fruit flavour and their production rates can increase during banana ripening (Tressl and Jennings 1972).

Over 80 volatile aroma compounds have been identified in guava fruit. The production of volatile chemicals has been shown to change during maturation of guava. As the fruit matures, the production of isobutanol, butanol and sesquiterpenes decrease, and in mature and ripe fruit, ethyl acetate, ethyl caproate, ethyl caprylate and *cis*-hexenyl acetate are high (Askar *et al.* 1986). More than 400 substances

have been shown to contribute to the odour of tomatoes, but no single compound or simple combination of these compounds has the typical smell of ripe fruit (Hobson and Grierson 1993).

Toxicity

Toxins may exist in unripe fruit that reduce as the fruit ripens. Tomatoes at the green stage of maturity contain a toxic alkaloid called solanine that decreases during ripening (Laval Martin *et al.* 1975). Ackee fruit contain the toxin hypoglycin in the arils, which gradually reduces as the fruit matures (Larson *et al.* 1994).

Controlled atmosphere storage on ripening

The level of CO₂ and O₂ in the surrounding environment of climacteric fruit can affect their ripening rate. Controlled atmosphere storage has been shown to suppress the biosynthesis of ethylene in ripening fruit, and in early work by Gane (1934), biosynthesis of ethylene was shown to cease in the absence of O₂. Ethylene concentrations in the core of apples were generally progressively lower with reduced O₂ concentrations in the store over the range of 0.5–2% O₂ (Stow 1989a). Wang (1990) reviewed the literature on the effects of CO₂ and O₂ on the activity of enzymes associated with fruit ripening and cited many examples of the activity of these enzymes being reduced in controlled atmosphere storage. This is presumably, at least partly, due to many of these enzymes requiring O₂ for their activity.

Quazi and Freebairn (1970) showed that high CO₂ and low O₂ delayed the high production of ethylene associated with the initiation of ripening in bananas, but the application of exogenous ethylene was shown to reverse this effect. Wade (1974) showed that bananas could be ripened in atmospheres of reduced O₂, even as low as 1%, but the peel failed to degreen, which resulted in ripe fruit which were still green. Similar effects were shown at O₂ levels as high as 15%. Since the degreening process in Cavendish bananas is entirely due to chlorophyll

degradation (Seymour *et al.* 1987a, 1987b), the controlled atmosphere storage treatment was presumably due to suppression of this process. Hesselman and Freebairn (1969) showed that ripening of bananas, which had already been initiated to ripen by ethylene, was slowed in low O₂ atmospheres.

Goodenough and Thomas (1980, 1981) also showed suppression of degreening of fruits during ripening; in this case, it was with tomatoes ripened in 5% CO₂ combined with 5% O₂. Their work, however, showed that this was due to a combination of suppression of chlorophyll degradation and the suppression of the synthesis of carotenoids, lycopene and xanthophyll. Jeffery *et al.* (1984) also showed that lycopene synthesis was suppressed in tomatoes stored in 6% CO₂ combined with 6% O₂.

Ethylene biosynthesis was studied in Jonathan apple fruits stored at 0°C under controlled atmosphere storage conditions of 0–20% CO₂ and 3 or 15% O₂. Fruits were removed from storage after 3, 5 and 7 months. Internal ethylene concentration, 1-aminocyclopropane 1-carboxylic acid levels and ethylene forming enzyme activity were determined in fruits immediately after removal from storage and after holding at 20°C for 1 week. Increasing CO₂ concentration from 0 to 20% at both low and high O₂ concentrations inhibited ethylene production by fruits. ACC levels were similarly reduced by increasing CO₂ concentrations even in low O₂; low O₂ enhanced ACC accumulation but only in the absence of CO₂. Ethylene forming enzyme activity was stimulated by CO₂ up to 10% but was inhibited by 20% CO₂ at both O₂ concentrations. The inhibition of ethylene production by CO₂ may, therefore, be attributed to its inhibitory effect on ACC synthase activity (Levin *et al.* 1992). In other work, storing pre-climacteric fruits of apple cultivars Barnack Beauty and Wagner at 20°C for 5 days in 0% O₂ with 1% CO₂ (99% nitrogen) or in air containing 15% CO₂ inhibited ethylene production and reduced ACC concentration and ACC synthase activity compared with storage in normal atmospheres (Lange *et al.* 1993).

Low O₂ and increased CO₂ concentrations were shown to have an effect on the decrease in ethylene sensitivity of Elstar apple fruits and Scania

carnation flowers during controlled atmosphere storage (Woltering *et al.* 1994). Storage of kiwifruit in 2–5% O₂ with 0–4% CO₂ reduced ethylene production and ACC oxidase activity (Wang *et al.* 1994). Ethylene production was lower in Mission figs stored at 15–20% CO₂ concentrations compared to those kept in air (Colelli *et al.* 1991).

Design of ripening rooms

The primary requirements for ripening rooms are that they should:

- have a good temperature control system,
- have good and effective air circulation,
- be gas-tight,
- have a good system for introducing fresh air.

Air circulation around the fruit is important to prevent local accumulations of the CO₂ given out by the fruit and to ensure good contact between the fruit and the ethylene gas applied to initiate ripening. In the case of bananas and some other types of fruit, the boxes are lined with polyethylene film and usually transported to ripening rooms stacked on pallets. Several systems have been used. One is to remove each box from the pallet, pull back the plastic film and re-stack them on pallets so that there is a space between boxes (Figure 66). In other cases, the pallets are stacked so that one handhold in each box is facing outwards. As the fruit are loaded into the rooms, the plastic just inside each handhold is torn to facilitate air exchange. This is especially important where fruit have been vacuum packed.

Air circulation systems are usually largely convective. Air is blown through the cooler and then across the top of the store just below the ceiling. The cooled air falls by convection through the boxes of fruit and is taken up at floor level for recirculation. Many modern ripening rooms have air channels in the floor through which air is circulated at high pressure. This forces it up through the pallets of boxes and should give better air circulation. Special devices such as inflatable air bags placed between pallets are now used to ensure better air circulation and, therefore, more even fruit ripening.

Good ventilation to enable fresh air to be introduced is very important for successful fruit ripening. During the period of initiation of ripening, which is



Figure 66 Conventional banana ripening room in Britain in 1986.

usually 24 h, no fresh air is introduced to the rooms. This is the period when ethylene is introduced. Directly after this period, the rooms must be thoroughly ventilated. In a study of bananas in Ecuador (Thompson and Seymour 1984), it was found that the CO₂ level of ripening rooms had gone up to 7% during this 24-h initiation period. Even with a good fan extraction system, it took 40 min of ventilation to bring the CO₂ levels to below 1%. This ventilation with fresh air must be repeated every 24 h during subsequent ripening to prevent levels of CO₂ becoming too high. If rooms are not frequently ventilated, ripening can be delayed, or abnormal ripening can occur.

The rooms need to be gas-tight in order to ensure that threshold levels of ethylene are maintained around the fruit during the initiation period. The most common place where leakage occurs is around the doors. It is, therefore, crucial that special gas-tight doors are fitted and that they have suitable rubber gaskets. These must be inspected regularly to ensure that they have not been damaged. Gas can also be lost through the walls of ripening rooms. Commonly, these are metal-lined on the inside with mastic

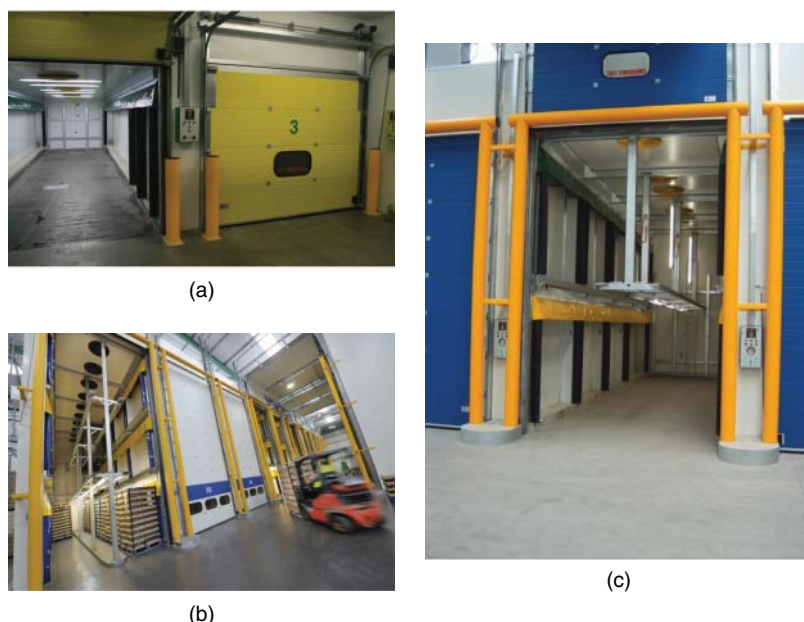


Figure 67 (a) Three-tier pressurised banana ripening system. (b) Two-tier 26-pallet banana ripening room. (c) Random access fruit ripening room typically used for the ripening of avocados and mangoes. (Source: MTX Contracts Ltd.) See colour plate section.

between joints to ensure no gas can pass through them. Gas-tight paint can be used on walls. All holes through the walls for plumbing and electrical fittings must be blocked with mastic.

During the 1990s, there was an increasing demand for all the fruit being offered for sale in a supermarket to be of exactly the same stage of ripeness so that it has an acceptable and predictable shelf life. This led to the development of a system called pressure ripening (Figure 67), which is used mainly for bananas but is applicable to any climacteric fruit. The system is the same as that described above, but it also involves direction of the circulating air so that it is channelled through the boxes of fruit. This results in the ethylene being in contact equally with all the fruit in the room. At the same time, the CO_2 is not allowed to concentrate around the fruit.

It is advisable to have high humidity of 90–95% r.h. in ripening rooms. To this end, many rooms are fitted with some humidification device such as a spinning disc humidifier. However, if the rooms are full of fruit and the refrigerant in the cooling coils used to maintain the room temperature is regulated to within a few degrees of the required room temperature, then this should be sufficient to keep the humidity high.

Ethylene on ripening

The change in physiology of climacteric fruit from maturation to ripening is initiated when cellular quantities of ethylene reach a threshold level. Processes controlled by ethylene have been classified into System 1 and System 2. Yang (1987) described them as follows: System 1 is where fruits produce low levels of ethylene and exogenous ethylene treatment does not stimulate further synthesis. In System 1, ethylene stimulates the process. If ethylene concentrations are increased, the process goes faster, and if ethylene concentrations are reduced or ethylene is removed completely, then the process slows or stops. This is the case for ethylene stimulation of the deterioration or senescence or discoloration of some vegetables, changes in non-climacteric fruit and the senescence of both non-climacteric and climacteric fruit. In contrast, System 2 is where the ethylene produced by ripening fruits is autocatalytic, stimulating its own synthesis. In System 2, ethylene acts as a switch that cannot be stopped. Thus, ethylene initiates the process. If ethylene levels are reduced or ethylene is removed completely, then the process continues. This is the process that occurs in the

ripening of climacteric fruit (Rees and Hammond 2002). McMurchie *et al.* (1972) defined System 1 as functioning during normal growth and development and during stress responses, whereas System 2 operates during floral senescence and fruit ripening. System 1 is autoinhibitory, such that exogenous ethylene inhibits synthesis, and inhibitors of ethylene action can stimulate ethylene production. In contrast, System 2 is stimulated by ethylene and is therefore autocatalytic, and inhibitors of ethylene action inhibit ethylene production.

Little ethylene, or ethylene precursors, has been detected in maturing fruits and it is not clear exactly what causes its rapid production and, thus, the beginning of the climacteric rise. However, the application of ethylene to fruit that are not yet fully mature can initiate the climacteric and the endogenous production of ethylene, for example to bananas (Biale 1950). In bananas, the principal source of ethylene is its biosynthesis in the fruit pulp (Ke and Tsai 1988). This increase in ethylene synthesis is followed by changes in the fruits' physiology, texture and

composition associated with ripening as described above, including the typical climacteric rise in respiration.

Threshold levels of ethylene will be reached naturally at fruit maturity, but it can also arise by the fruit being put under stress during production by water shortage or infection by disease-causing organisms or by mechanical damage to the fruit during harvesting and handling operations. Exposing fruit postharvest to low humidity may also result in sufficient stress to the fruit to initiate ripening. This was shown by Thompson *et al.* (1974) for plantains. The threshold level can also be achieved by exposing the fruit, for a sufficient period, to a threshold concentration of ethylene in a gas-tight room. This is the principal used in most commercial fruit ripening rooms. Wills *et al.* (1999) showed a 60% extension in the postharvest life of a range of fruit and vegetables when stored in about 5 ppb compared with 100 ppb ethylene. Sources of ethylene, ethylene application methods and alternatives to ethylene are dealt with under the section on banana ripening.

12

Specific recommendations for fruit

Abiu

Sapotaceae

Pouteria caimito Radlk., *Lucuma caimito* Roem. & Schult., *Achras caimito* Ruiz & Pavón. In Colombia, it is called caimito, caimito amarilla, caimo or madura verde; in Ecuador, *luma* or *cauje*; in Venezuela, *temare*; and in Brazil, *abiu*, *abi*, *abio*, *abieiro* or *caimito*. It is called yellow star apple in Trinidad (Morton 1987).

The tree is evergreen up to 8 or 10 m high, attractive and fruitful on a range of soils from clay to limestone and tolerant of drought. The fruit are orange-yellow in colour when mature and pointed, globose or ovoid in shape and 5–12 cm long. The sweet pulp is also orange in colour and mealy in texture and has up to three dark brown shiny seeds. It is usually eaten raw (Kennard and Winters 1960, Purseglove 1975, Morton 1983). The chemical content was given by Morton (1987) in Table 44. The fruits were said to keep well (Morton 1983), and storage at 1 or 3 °C for 17 days did not cause appreciable loss of fruit quality compared to fruit stored at 10 °C (Hallman 1995). In contrast, SeaLand (1991) recommended 12.8 °C and 85–90% r.h. for 21 days. At 1 °C, 14 days would be needed to achieve quarantine security to control Caribbean fruit fly (*Anastrepha suspensa*), while at

3 °C a minimum of 15 days would be required. Hot water treatment at 46 °C for 90 min or at 48 °C for 65 min resulted in the development of dark blotches on the peel and a 2–3-mm thick layer under the peel that did not soften (Hallman 1995).

Abiyuch

Capparaceae

Crateva religiosa J.G. Forster, *C. religiosa* Blanco, *C. macrocarpa* Kurz., *C. Adansonii*. Other common names include Garlic Pear, Sacred Garlic Pear, Temple Plant, Balai Lamok, Barna, Varuna and Bidasi. It is native of south east Asia, Japan, Australia and the south Pacific islands and is distributed from India throughout South and Southeast Asia to Micronesia and Polynesia, Borneo, New Guinea and the Solomon Islands, Australia, much of south east Asia and several south Pacific islands wild. It is occasionally cultivated usually below 100 m altitude, but also grows up to 700 m altitude. The tree grows up to 30 m high with greyish bark and is sometimes called the spider tree because the showy flowers that are borne in rachis. It is grown for its fruit, especially in parts of Africa. The chemical content was given by USDA (2012) in Table 45.

Table 44 The composition of the edible portion from Costa Rica and El Salvador of canistel for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	64.6–67.4 g	Phosphorus	24.5–29.1 mg
Protein	0.230–0.291 g	Iron	0.52–1.70 mg
Fat	0.26–0.49 g	Carotene	0.157–0.273 mg
Fibre	0.9–2.5 g	Thiamine	0.005–0.16 mg
Ash	0.96–1.61 mg	Riboflavin	0.013–0.027 mg
Calcium	10.5–33.2 mg	Niacin	1.466–1.530 mg
		Ascorbic acid	11.0–35.6 mg

Table 45 The composition of abiyuch fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	79.90 g	Total ascorbic acid	54.1 mg
Energy	69 kcal	Iron	1.61 mg
Protein	1.50 g	Magnesium	24 mg
Total lipid (fat)	0.10 g	Phosphorus	47 mg
Carbohydrate, by difference	17.60 g	Potassium	304 mg
Total dietary fibre	5.3 g	Sodium	20 mg
Total sugars	8.55 g	Zinc	0.31 mg
Vitamin A	100 iu	Calcium	8 mg
Vitamin A	5 µg RAE	Fatty acids, total saturated	0.014 g

Açaí

Arecaceae, Palmae

Euterpe oleracea Martius. Açaí are tall, slender palms growing to 15–30 m high with pinnate leaves up to 3 m long. The fruit is a drupe containing a single seed, which accounts for some 87% of the mass. It is indigenous to South America where it is the predominant canopy plant inside the Amazon River delta in Para and Amapa states of Brazil, covering a range of over three million hectares (Kang *et al.* 2010). The State of Para produced some 96% of açaí fruit in Brazil, followed by the states of Acre, Amazonas and Amapa with only about 1% in each (de Oliveira *et al.* 2011). It produces edible fruit and the tree can also be harvested for palm hearts.

A drink is prepared from the fruit in the north of Brazil by soaking the fruit in warm water. Pessoa and da Silva e Silva (2007) carried out experiments to evaluate the effect of water temperature on water absorption at 0–39 °C. They concluded that water imbibition rate was temperature related and absorption was a minimum at 13 °C. They also found that fruit stored at 10 °C with 81–87% r.h.

for 5 days had an increased water absorption rate. In a study of the natural juice from one state in Brazil, de Oliveira *et al.* (2011) found contamination by total and heat-tolerant coliforms at 45 °C, moulds and yeasts and concluded that the hygienic-sanitary conditions made the juice both unsatisfactory and unsafe for consumption. This clearly does not affect the characteristics of the fruit but does point to the importance of hygiene in processing establishments.

It was reported to be non-climacteric (Bichara and Rogez 2011, Aguiar *et al.* 2013). Açaí fruit exhibited extremely high anti-oxidant capacity, and Kang *et al.* (2010) identified the major flavonoids in açaí pulp as homoorientin, vitexin, luteolin, chrysoeriol, quercetin and dihydrokaempferol and confirmed that flavonoids were the major polyphenols. Anthocyanins and proanthocyanidins concentrations were relatively low contributing only about 10% to the overall anti-oxidant capacity of açaí fruit (Lichtenhäler *et al.* 2005).

Bichara and Rogez (2011) reported that harvest maturity is based on peel colour and give the following characteristics for the 'black' variety that represents more than 95% of the commercially produced fruit in Brazil:

- Green – at least half the peel is still green;
- Slightly mature (*vitrin*) – most of the peel is black;
- Black – peel completely black and shiny;
- Tuira – black with a thin layer of wax that gives them a white appearance;
- Over ripe – the peel has begun to dry out.

At the second stage the fruits were not fully ripe but could be harvested and marketed, but pulp production was low. The fourth appeared to be optimum. They also recommend the optimum storage temperature for fruits as between 10 and 15 °C.

Aguiar *et al.* (2013) compared transport of açaí fruit in boats on the Brazilian Amazon as stowage in closed polystyrene boxes in cargo holds (which is the most common method) with open baskets in the prow or bow of the boat. Fruit in the polystyrene boxes showed spontaneous fermentation of alcoholic, acetic and lactic types. They concluded that an open system, giving continuous aerobic conditions, and a short period of time between harvesting and processing were preferable for transporting the fruit.

Acerola

Malpighiaceae

Malpighia emarginata Sessé & Moc. ex DC., synonymous with *M. biflora* Poir., *M. glabra* L., *M. puniceifolia* L. and *M. retusa* Benth., also called Barbados cherry, West Indian cherry and wild crepe myrtle. There is some confusion in the literature between the names acerola and Barbados cherry or West Indian cherry. Other species include *M. emarginata* DC, *M. biflora* Poir and *M. retusa* Benth. It is native to South America, southern Mexico and Central America and originated in the Yucatan area of Mexico. It is now cultivated throughout South America and the southern states of the United States and throughout the tropics and subtropics in many parts of the world.

It is a tropical or subtropical, branched shrub varying in shape from low and spreading to a more upright and open habit that can grow up to 5 m high. It has slender branches with shiny light to deep green leaves. The hermaphrodite flowers are 1–2 cm in diameter borne in axillary cymes. The fruit is a fleshy drupe that is borne in leaf axils, singly or in clusters of two or three. They have a bright red skin when ripe and three lobes each containing a triangular seed (Purseglove 1975).

Among 150 constituents, the major components identified in the aroma concentrate were furfural, hexadecanoic acid, 3-methyl-3-buten-1-ol and limonene. It was also conjectured that the amounts of esters seemed to contribute to the unique flavour of the acerola fruit (Pino and Marbot 2001). They are extremely rich in ascorbic acid with up to 4000 mg 100 g⁻¹ of the pulp (Purseglove 1968) and 1000–4500 mg 100 g⁻¹ of fruit (Pino and Marbot 2001). Charley (1969) gave the following ascorbic acid content in mg 100 g⁻¹ as 1707 for Puerto Rica, 1996 for Florida, 1130 for Venezuela, 1900 and 2520 for Mexico, 1100 for Colombia and 2233 for Hawai'i. Mezadri *et al.* (2008) reported that it has the highest vitamin C content measured in any fruit as well as high levels of vitamins A, B1, B2 and B3 and carotenoids and bioflavonoids. However, Alves *et al.* (1995) found that fruits harvested while still green lost 33% vitamin C up to the pink stage and 45% when dark red. They also reported that fruits harvested at the pink stage had at least 6.5% TSS. These results confirmed those reported by Charley (1969) in Table 46. Mezadri *et al.* (2008) commented

Table 46 Ascorbic acid content of acerola fruit during development (source: adapted from Charley 1969)

Days after petal fall	Diameter (mm)	Colour	Ascorbic acid (mg 100 ⁻¹)
7	2	Green	4500–6000
14	5	Green	4000
21	8–10	Pink to white	3500
28	10–25	Full red or yellow	1300–2500

that their nutrient composition depended on the species of *Malpighia* and environmental conditions, but the most common components for 100⁻¹ fresh weight were proteins 2.1–8.0 g, lipids 2.3–8.0 g, carbohydrates 35.7–78.0 g, calcium 117 mg, phosphorus 171 mg, iron 2.4 mg, pyridoxine 87 mg, riboflavin 0.7 mg, thiamine 0.2 mg, water 906–920 g and dietetic fibre 30 g. The chemical content was given by USDA (2012) is shown in Table 47.

Harvesting

Trees should produce fruit the 2nd year after planting. Fruits should be harvested frequently since they deteriorate quickly if left on the tree. They are normally harvested when their skins are pinkish orange to light red in colour. Carrington and King (2002) found that horticultural maturity was reached when fruit showed colour break, which was 18 days after

Table 47 The composition of acerola, West Indian cherry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	91.41 g		
Energy	32 kcal	Total ascorbic acid	1677.6 mg
Protein	0.40 g	Thiamine	0.020 mg
Total lipid (fat)	0.30 g	Riboflavin	0.060 mg
Carbohydrate, by difference	7.69 g	Niacin	0.400 mg
Fiber, total dietary	1.1 g	Vitamin B-6	0.009 mg
Calcium	12 mg	Folate	14 µg DFE
Iron	0.20 mg	Vitamin B-12	0.00 µg
Magnesium	18 mg	Vitamin A	38 µg RAE
Phosphorus	11 mg	Vitamin A	767 IU
Potassium	146 mg	Fatty acids, total saturated	0.068 g
Sodium	7 mg	Fatty acids, total monounsaturated	0.082 g
Zinc	0.10 mg	Fatty acids, total polyunsaturated	0.090 g



Figure 68 Experimental tree shaker and catcher being used for apples in the United Kingdom in the 1970s.

anthesis. Harvesting is done by hand, although tree shakers (Figure 68) have been tried (Pantastico 1975). Fruits harvested green had the highest ascorbic acid levels, but their eating quality was not as desirable as those of ripe fruits (dos Santos *et al.* 1999).

Postharvest physiology

Alves *et al.* (1995) reported that respiration rate of fruits at yellow-green and pink stages suggested a climacteric pattern. This was confirmed by Carrington and King (2002) who found that they had a very high peak respiratory rate of $900 \text{ ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ but a low peak ethylene production of $3 \mu\text{l kg}^{-1} \text{ h}^{-1}$.

Storage

Storage of fruit at $4\text{--}7^\circ\text{C}$ with 60% r.h. maintained their quality but they still quickly became soft. Freezing was more efficient than cold storage in reducing ascorbic acid losses and changes in the level of acidity (dos Santos *et al.* 1999). Another refrigerated storage recommendation was 0°C and 85–90% r.h. for about 8 weeks (Pantastico 1975, SeaLand 1991).

Fruits harvested at the pink stage could be stored in PVC film bags at room temperature for 2 or 3 days and at 8°C and 85–90% r.h. in PVC bags they could be stored for a week (Alves *et al.* 1995).

Achachairú

Guttiferae, Clusiaceae

Rheedia laterifolia L., *Garcinia humilis* (Vahl.) C.D. Adam. The tree grows up to 12 m high and is native to Bolivia. The flowers are borne in the leaf axils and are hermaphrodite; although some trees produce only male flowers. The fruit is a berry up to 5.2 cm long and 4 cm wide with a thick, hard green skin containing white translucent edible pulp that comprises some 40% of its weight. The peel accounts for 47% and the seeds 13% (Duarte and Paull 2008, Duarte 2011). Ardaya *et al.* (1995, quoted by Duarte 2011) reported that the fresh pulp contained 83.9% water, 14.2% total carbohydrate, 0.4% protein, 0.5% fat, 0.6% fibre and 0.3% ash.

Duarte (2011) reported that it was a climacteric fruit and optimum harvest maturity is judged by peel colour when it changes from yellow to orange with brownish tint. He also reported that storage at 6°C resulted in chilling injury, and Duarte and Paull (2008) reported beneficial effects of storage in PVC film bags. They recommended 12°C in PVC bags for up to 3 weeks.

African fan palm

Arecaceae, Palmae

Borassus aethiopum Mart. synonymous with *B. flabellifer* L. var. *aethiopicum* Warb. It grows naturally throughout the semi-arid to sub-humid regions of the African savannas from Senegal to the Central African Republic. Ali *et al.* (2010) reported that over 60% of the annual fruit yield of *B. aethiopum* was often lost within 10 days after harvesting because of rotting. The trees are dioecious that grow up to 25 m tall. The young stem has clasping leaf bases that become smooth and are up to 4 m long. A swelling usually occurs on the trunk above the middle when it is over 50 years old. The male spadix is about 2 m long with poke-like branches and the female spadix is not branched. The inflorescences are tapped to make

palm wine or distilled to produce arrack. Fruits are subglobose about 12.5×15 cm cupped in a calyx and orange in colour with fibrous yellow pulp containing three hard coated seeds (Purseglove 1975). In the Cameroon the pulp of *B. aethiopum* constituted 35% of the total mass of the fruit, and there were significant differences in fruit morphology and similarity in nutritional composition per 100 g of fresh matter was observed greater than 4.47 g sugars, 5.18 g fibre, greater than 26 mg of provitamin A and greater than 134.82 mg vitamin C 100 g^{-1} (Ali *et al.* 2010).

African pear

Burseraceae

Dacryodes edulis (G. Don) HJ Lam. Other common names include nsafu, bush butter tree, ube and safou. Originating in Central Africa and the Gulf of Guinea region, the popularity of fruit has led to its widespread cultivation, extending from Sierra Leone in the west to Uganda in the east and northern Angola in the south (Awono *et al.* 2002). It is grown in Cabinda, Cameroon, Congo Brazzaville, Congo Kinshasa, Gabon, Ghana, Equatorial Guinea, Nigeria and Sao Tome. It is commonly cultivated in agro-forestry systems as a shade tree and secondary crop in cocoa and coffee farms. Its natural habitat is the humid tropical forest (Onuegbu *et al.* 2011). It grows up to 40 m high with a relatively short trunk with yellow flowers about 5 mm across produced in large inflorescences. The fruit is an ellipsoidal drupe that is up to 12 cm long with dark bluish-black-coloured skin and pale to light green flesh (Onuegbu *et al.* 2011).

Harvest maturity of the fruit is based on skin colour, which changes from pink in the developing fruit to bluish-black when fully mature. From the 17th to the 21st week after fruit set, the fruit quality remained constant except in the skin colour change and can be successfully harvested at any time during that period (Onuegbu *et al.* 2011).

Awono *et al.* (2002) commented that the main constraint to both the domestic and the international trades was its high perishability. Poulton and Poole (2001, quoted by Awono *et al.* 2002) found that their perishability made marketing inherently more uncertain and they placed a premium on good infrastructure including cold storage chains for high value markets for developing the trade in the fruit.

Nwanekezi (n.d.) showed that the rates of growth of microorganisms, moisture loss, weight loss, browning and softening rates increased rapidly during storage of the fruit at ambient temperature of some 30°C . Storage at 5°C resulted in reduced microbiological growth, and in ambient humidity they had an average shelf life of 27 days, while at 5°C and 65–81% r.h. their shelf life was an average of 31 days. At 10°C and 65–81% r.h. they had an average shelf life of 24 days and in ambient humidity they had an average shelf life of 18 days.

Amelanchier

Rosaceae

Amelanchier alnifolia Nutt. also called Saskatoon Serviceberry, Pacific Serviceberry and Western Serviceberry. Several varieties have been recognized. It is a native of western North America from Alaska across most of western Canada and in the western and north central United States from sea level in the north of the range, up to 2600 m in California and 3400 m in the Rocky Mountains (Harris 1976). It is a deciduous shrub or small tree normally up to 8 m in height and produces suckers forming clumps. The flowers are white, 2–3 cm in diameter and produced in racemes. The fruits are black when ripe (Harris 1976). The chemical content was given in Table 48. The cultivars Pembina, Smoky, Northline and Thiessen were stored at 0.5°C in 2, 10 and 21% O_2 factorially combined with either 0.035 or 5% CO_2 for 56 days by Rogiers and Knowles (2000). They found that controlled atmospheres improved storage of all four cultivars compared to those stored in air. The 5% CO_2 + 21 or 10% O_2 was most effective at minimizing losses in TSS, anthocyanin, firmness and fresh weight and ethanol did not exceed 0.03% in fruits stored in any of the atmospheres. Fungal infection by *Botrytis cinerea* occurred on fruits stored in air after 8 weeks but not on those stored in 5% CO_2 + 21 or 10% O_2 .

Amazon tree grape

Moraceae, Urticaceae

Pourouma cecropiaefolia Mart., synonymous with *P. multifida*. The tree grows wild in the western part of Amazonas and adjacent areas of Brazil, Ecuador

Table 48 The composition of raw Saskatoon berries for 100 g⁻¹ fresh weight (source: Mazza 2005. Reproduced with permission from Taylor & Francis)

Energy	85 kcal	Vitamin C	3.6 mg
Total dietary fibre	5.9 g	Vitamin A	11 IU
Total sugars	11.4 g	Vitamin E	1.1 mg
Calcium	42 mg	Folate	4.6 mcg
Magnesium	24 mg	Riboflavin	3.5 mg
Iron	1 mg	Panthenic acid	0.3 mg
Manganese	1.4 mg	Pyridoxine	0.03 mg
Potassium	162 mg	Biotin	20 mcg
Sodium	0.5 mg		

and Peru on high dry land at altitudes below 500 m. It grows well in poor upland soils. It is especially abundant in the vicinity of Iquitos and has been cultivated since pre-Hispanic times by the Indians of south-western Colombia and is grown in Brazil especially by the Indians. The tree is up to 15 or 20 m in height with grey bark marked with leaf scars. The white male and female flowers are borne on separate trees in bunches of 20 or more. The fruit is round or round-ovate usually 0.5–1 cm in diameter but occasionally up to 4 cm. The skin is very rough, inedible but easily peeled and purple when ripe. The pulp is white, mucilaginous and juicy with a sub-acid, very mild flavour and contains a conical seed with a fibrous, grooved coat. The fruit is susceptible to fungal attacks and does not keep well, which limits its commercial viability (Morton 1987).

Anthora

Solanaceae

Solanum macrocarpon L. synonymous with *S. indicum* L., *S. integrifolium* Poir. var. *macrocarpum*, *S. melongena* L. var. *depressum* Bail. Other common names include African eggplant and scarlet eggplant. It originated in Africa and is grown primarily for its fruit but young leaves can be consumed raw, cooked or steamed. The fruits are usually cooked and used in curry and soup and can be cooked like aubergine (*Solanum melongena*). It is also grown in India and Malaysia where mature acidic fruits are used as a sour relish. In Indonesia and Suriname the bitter fruits are eaten cooked with rice. It is also grown in the Caribbean particularly Barbados from where it is exported (Medlicott 1990). It also has medical uses and the root is used against bronchitis

and for body aches as well as to control asthma and to cure wounds while the seeds are used to treat toothache. A glabrous, erect or climbing, unarmed, herbaceous plant up to 1.5 m tall with a blackish violet stem that is woody at the base. The fruits are depressed globose in shape, up to about 6 × 8 cm and orange-yellow in colour. It is a small tropical perennial up to about 1 m tall, has oblong-lanceolate leaves and white-pink flowers. Fruit have a bright green calyx and pale creamy to white skin and are some 5 cm in diameter.

Leaves may be harvested after 40–50 days and the fruit after 80–100 days after planting preferably in the early part of the day. Pedicels should be cut with secateurs since breaking or twisting can cause damage both the fruit and the plant to a maximum of 1 cm to minimize fruit-to-fruit damage during handling. They are highly susceptible to browning of the skin, both before and after harvest. Browning is may be a stress response and they should be handled carefully and shaded from the direct sun. The time between harvesting and cool storage should be minimized. For export they are washed to remove soil and insects from under the calyx, either in running or chlorinated water. The fruit should be packed when dry (Medlicott 1990).

Storage at 12 °C was recommended because they are susceptible to chilling injury at temperatures below 10 °C. Chilling injury symptoms include browning, shrivelling and pitting of the surface (Medlicott 1990). He also reported that the effects of ethylene exposure were not known, but separation from ethylene producing products may be advisable.

Apples

Rosaceae

Malus sylvestris (L.) Mill. var. *domestica* (Borkh.) Mansf., *M. × domestica* Borkh. It originated in western Asia, and its progenitor was reported to be *M. sieversii* (Velasco *et al.* 2010), which is still found growing wild in the mountains of Central Asia in southern Kazakhstan, Kyrgyzstan, Tajikistan and China. Apples have been grown for at least 3000 years in Asia and Europe. There are thousands of cultivars bred for eating fresh as well as for cooking and cider production (Pierre-éric *et al.* 2006). Total world production in 2010 was given by FAO (2013) as 69,511,975 tonnes. They also reported on

Table 49 World production in tonnes of apples in 2011 (source: adapted from FAO 2013)

Afghanistan	59,469	Kyrgyzstan	158,300
Albania	56,000	Latvia	7,501
Algeria	450,000	Lebanon	150,000
Argentina	1,115,950	Libya	19,900
Armenia	77,602	Lithuania	49,099
Australia	299,778	Luxembourg	2,130
Austria	546,741	Madagascar	6,523
Azerbaijan	223,067	Malta	42
Belarus	192,819	Mexico	630,533
Belgium	228,405	Montenegro	7,472
Bhutan	17,227	Morocco	506,119
Bolivia (Plurinational State of)	1,922	Nepal	42,704
Bosnia and Herzegovina	75,334	The Netherlands	418,000
Brazil	1,339,000	New Zealand	437,782
Bulgaria	40,413	Norway	12,831
Canada	390,362	Occupied Palestinian Territory	1,250
Chile	1,169,090	Pakistan	598,804
China	35,987,221	Paraguay	699
Colombia	1,219	Peru	149,532
Croatia	112,931	Poland	2,493,080
Cyprus	7,012	Portugal	247,229
Czech Republic	84,594	Republic of Korea	379,541
Democratic People's Republic of Korea	806,718	Republic of Moldova	268,842
Denmark	32,170	Réunion	36
Ecuador	8,977	Romania	620,362
Egypt	455,817	Russian Federation	1,200,000
Estonia	2,702	Saint Vincent and the Grenadines	1,806
Finland	5,249	Serbia	265,576
France	1,858,880	Slovakia	31,355
Georgia	64,300	Slovenia	105,355
Germany	898,448	South Africa	781,124
Greece	255,800	Spain	670,566
Grenada	541	Swaziland	–
Guatemala	20,684	Sweden	20,684
Honduras	224	Switzerland	360,863
Hungary	292,810	Syrian Arab Republic	307,760
India	2,891,000	The former Yugoslav Republic of Macedonia	124,552
Iran (Islamic Republic of)	1,651,840	Tunisia	128,000
Iraq	45,948	Turkey	2,680,080
Ireland	43,064	Turkmenistan	76,533
Israel	119,231	United Kingdom	233,750
Italy	2,411,200	United States of America	4,272,840
Japan	655,300	Uruguay	73,368
Jordan	39,653	Uzbekistan	779,000
Kazakhstan	114,000	Yemen	19,079
Kenya	779	Zimbabwe	6,090

production in individual countries with the China being by far the largest producer (Table 49). It is a deciduous tree growing up to 12 m high but usually much smaller, often grafted onto dwarfing rootstocks. The fruit is a pome and is classified as climacteric. In 2010, the fruit's genome was decoded, which will

lead to new understandings of disease control and selective breeding for the various aspects of apple production. Their freezing point was reported to be about -2.8 to -2.5 °C (Wright 1942). Malic acid is the major organic acid but some apples contain quantities of citric acid and some pears contain quantities of

Table 50 The composition of apple fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	85.56 g	Thiamine	0.017 mg
Energy	52 kcal	Riboflavin	0.026 mg
Protein	0.26 g	Niacin	0.091 mg
Total lipid (fat)	0.17 g	Vitamin B-6	0.041 mg
Carbohydrate, by difference	13.81 g	Folate	3 µg DFE
Total dietary fibre	2.4 g	Vitamin B-12	0.00 µg
Total sugars	10.39 g	Vitamin A	3 µg RAE
Calcium	6 mg	Vitamin A	54 IU
Iron	0.12 mg	Vitamin E	0.18 mg
		(α-tocopherol)	
Magnesium	5 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	11 mg	Vitamin D	0 IU
Potassium	107 mg	Vitamin K	2.2 µg
		(phyloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.028 g
Zinc	0.04 mg	Fatty acids, total monounsaturated	0.007 g
Total ascorbic acid	4.6 mg	Fatty acids, total polyunsaturated	0.051 g

Table 51 The composition of crab apple fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	78.94 g	Total ascorbic acid	8.0 mg
Energy	76 kcal	Thiamine	0.030 mg
Protein	0.40 g	Riboflavin	0.020 mg
Total lipid (fat)	0.30 g	Niacin	0.100 mg
Carbohydrate, by difference	19.95 g	Vitamin B-12	0.00 µg
Calcium	18 mg	Vitamin A	2 µg RAE
Iron	0.36 mg	Vitamin A	40 IU
Magnesium	7 mg	Fatty acids, total saturated	0.048 g
Phosphorus	15 mg	Fatty acids, total monounsaturated	0.012 g
Potassium	194 mg	Fatty acids, total polyunsaturated	0.088 g
Sodium	1 mg		

quinic acid (Ulrich 1970). The chemical content was given by USDA (2012) in Table 50, and for crab apple the chemical content was given by USDA (2012) in Table 51.

Preharvest factors

Link (1980) showed that high rates of application of nitrogen fertilizer to apple trees could adversely affect

the flavour of the fruit. For good storage quality Cox's Orange Pippin, it was found that they required the following composition, on a dry matter basis for storage until December at 3.5 °C: N 50–70%, P 11% minimum, K 130–160%, Mg 5% and Ca 5%. For storage until March they required 4 °C with 2% O₂ and less than 1% CO₂ and 4.5% (Sharples 1980). Daminozide applied to tree can improve storage (Sharples 1967), but it has been withdrawn from the market in several countries (John Love, personal communication, quoted by Thompson 1996).

Harvest maturity

Selection of the correct maturity for harvesting is often a matter of experience on the part of the grower. They should be harvested just as they begin to ripen for good quality and in order to have a good storage and marketable life. There are a variety of techniques that are used or could be used to increase the precision. In order to determine the maturity of fruit various techniques have been developed and these are discussed in the following. All the tests, except the colour test and the time test, involve harvesting representative samples.

Colour

Skin colour can change during maturation and charts are used for some cultivars of apple, but it is not a reliable method since the changes tend to be subtle and vary depending on climate and weather conditions. However, Bertone *et al.* (2012) reported that there was a reduction in chlorophyll content of fruit as they mature, but this was masked in red apples. They found that variation in the chlorophyll content, measured by DR-UV-vis spectroscopy of the cultivar Scarlet before harvest, was a reliable indicator of the ripeness stage.

Time

The time between flowering and fruit being ready for harvesting may be quite constant, which gives an approximate guide to when fruit should be harvested. Usually this is measured from petal fall as it is easy to determine by observing when the bulk of the petals are on the ground around the tree.

Starch

Starch is converted into sugar as harvest time is approached, and the assessment of starch content

is done with the starch/iodine test (Cockburn and Sharples 1979) (Figure 6). Studies using this technique on apples gave inconsistent results in England, but in some other countries, for example in Turkey, it works well on apples and excellent charts have been produced by Dr Umit Ertan, Dr Sozar Ozelkok and Dr Kenan Kaynaş at the Atatürk Horticultural Research Institute in Yalova for individual cultivars (Figure 7).

Firmness

Pressure testers were first developed for apples (Magness and Taylor 1925) and are currently available in various forms (Figure 5). Firmness is usually expressed as kgf (kilograms force).

Vibration and acoustic tests

Equipment puts vibration energy into a fruit and measures its response to this input have been tested but not used commercially.

Near-infrared reflectance

Peirs *et al.* (2000) showed for Jonagold, Golden Delicious, Elstar, Cox's Orange Pippin and Boskoop apples that it was possible to use NIR spectroscopy as a non-destructive technique for measuring internal apple quality. Bertone *et al.* (2012) used NIR and UV-vis data to predict the optimal harvesting time of Scarlet apples. Correlations between sugar content and NIR measurement have also been shown by Kouno *et al.* (1993a) but it was not used commercially.

Nuclear magnetic resonance

NMR has also been shown to correlate well with sugar content of apples (Cho and Krutz 1989) but it is currently not used commercially. Lu and McCarthy (2012a) reported using NMR relaxometry for detecting black heart in pomegranates.

Mendoza *et al.* (2012) compared acoustic firmness, bioyield firmness, visible and shortwave near-infrared (Vis-SWNIR) spectroscopy and spectral scattering for assessing the firmness and/or TSS of Jonagold, Golden Delicious and Delicious apples. They found that the combination of Vis-SWNIR and scattering data improved TSS predictions for Delicious apples and demonstrated that the fused systems provided more complete and complementary information and were therefore more effective than individual sensors in prediction of apple quality.

In general, assessment of harvest maturity is based on a combination of several methods. For example for Pink Lady Gualanduzzi *et al.* (2005) reported that the best storability and quality were attained after 60–120 days of storage at 0 °C with fruit harvested with the following maturity indices: light green-yellow ground colour (L^* 69–71, a^* –9 to –11, b^* 40–43), firmness 7.5–8 kgf, starch degradation 2.8–3.2 (scale 1–5), TSS 15% and TA 1–1.3 Meq 10 ml^{–1}. They found that texture and flavour attributes with values lower than 6 kgf for firmness, 15% for TSS and 0.7 Meq 10 ml^{–1} for TA were not appreciated by a trained panel.

Harvest methods

Apples were traditionally grafted on rootstocks that resulted in tall trees that made them difficult to harvest. Traditionally the harvester would carry a ladder and use that to reach the fruit. A picking box could be used and worn around the harvester's neck. Fruit may be transferred from these to a pallet box to be taken and stacked in the storage chamber or taken to the packhouse. Types of package and the material from which they are made vary considerably. Hand harvesting is very time consuming and various ways have been developed to speed up the operation. A long pole with a bag at the end together with some device for cutting or breaking the fruit stalk has been used. Picking platforms are available that enable the harvester to be towed around the orchard from tree to tree so the platform can be raised and lowered enabling the fruit to be picked (Figure 13). Subsequently dwarfing rootstocks were developed at East Malling in Kent and at Merton in Cambridge and called Malling = M and Malling Merton = MM. These were developed for different purposes including vigour, yield, cultivar compatibility but some were dwarfing that may contain their size to some 2 m high to facilitate harvesting. Apple trees grown on a hedgerow system could be harvested with combing fingers giving 85% Grade 1 fruit; although a significant proportion of the fruit remained on the trees (LeFlufy 1983). The meadow orchard system is where the whole of the tree is harvested just above the ground every other year.

Prestorage treatments

A variety of chemicals have been applied to apples before storage including calcium, or lecithin, *N*

dimethylamino succinamic acid, diphenylamine, Nutri-Save, Semperfresh 1-MCP and various chemical fungicides. These chemicals leave residues, and pre-treatment with diphenylamine, folpet and imazalil was measured after storage at 1 °C in air, 2% O₂ + 2% CO₂ or 1% O₂ + 1% CO₂. After 27 weeks plus 7 days at 20 °C diphenylamine and folpet levels in apple skin were lower for fruit that had been stored in air or 2% O₂ + 2% CO₂ than for those had been stored in 1% O₂ + 1% CO₂. An additional storage period of 4 weeks in air reduced diphenylamine and folpet contents in whole apples stored for 13 weeks in the 2% O₂ + 2% CO₂. For imazalil, the same result was obtained in apple skins stored for 27 weeks under in 1% O₂ + 1% CO₂ (Villatoro *et al.* 2009). The postharvest application of calcium can also be used for apples to reduce the development of physiological disorders occurring during storage, particularly bitter pit. Drake and Spayd (1983) pressure infiltrated Golden Delicious apples with calcium chloride at 3% at 3 pounds per square inch for 8 min., before storage for 5 months at 1 °C. These fruit were firmer and more acid than untreated fruit stored for the same period of storage.

1-MCP

Positive effects of 1-MCP are mainly related to physiological processes especially those related to ethylene biosynthesis and susceptibility. Positive effects have been shown on many apple cultivars. Bulens *et al.* (2012) found that when Jonagold apples were treated with 1-MCP, ethylene biosynthesis was almost completely suppressed throughout the whole postharvest life, with the exception of late harvested apples that regained some ethylene forming capacity after 2 weeks of shelf life. Ethylene production, respiration rate and colour changes in Fuji apples were all inhibited following 1-MCP treatment at 0.45 mmol m⁻³ (Fan *et al.* 1999). The threshold concentration of 1-MCP inhibiting *de novo* ethylene production and action was 1 µl L⁻¹. 1-MCP-treated McIntosh and Delicious apples were significantly firmer than non-treated apples following cold storage and post-storage exposure to 20 °C for 7–14 days (Rupasinghe *et al.* 2000). de Wild (2001) made a single application of 1-MCP directly after harvesting to Jonagold and Golden Delicious apples, followed by 6 months of storage at 1 °C in 1.2% O₂ + 4% CO₂

or storage in air at 1 °C followed by shelf-life of 7 days at 18 °C. No loss of firmness was found after the use of 1-MCP and yellow discoloration of Jonagold decreased. Cold-stored apples showed greater softening than CA-stored apples, unless treated with 1-MCP. Treated apples did not show firmness losses during subsequent shelf life. Exposure to 1-MCP improved flesh firmness retention and reduced ethylene production of Scarletspur Delicious and Gala after storage in 0 °C both in air and 2% O₂ + less than 2% CO₂ (Drake *et al.* 2006). In McIntosh 1-MCP treatment reduced internal ethylene concentrations and maintained firmness of fruit during storage compared to the non-treated controls (Robinson *et al.* 2006). Moya-Leon *et al.* (2007) stored Royal Gala at 0 °C and 90–95% r.h. for 6 months followed by 7 days at ambient. They found that fruit stored in CA of 2.0–2.5% CO₂ + 1.8–2.0% O₂ or those treated with 625 nl L⁻¹ 1-MCP and stored in air had reduced ethylene production, softening and acidity loss and were preferred by consumers since their preferred textural characteristics were said to be maintained. However, storage in air gave the highest levels of aromatic volatiles, which were depressed by CA storage and 1-MCP treatment. 42 mol m⁻³ of 1-MCP for 24 h at 20 °C inhibited ethylene production regardless of storage temperature over the range of 0–20 °C. Results indicated that 1-MCP is an effective means that can be used to delay ripening and to retain fruit quality during transport and retailing at 10 or 20 °C of Fuji.

Variability in response to 1-MCP has been shown, not only to the concentration used and exposure time, but to the location of the orchard where the apples were grown. At one site McIntosh treated with 1-MCP had more internal browning but there was no effect at another (Robinson *et al.* 2006). In general a lower dose combined with shorter treatment time resulted in the highest internal ethylene concentration in Cox's Orange Pippin and Bramley's Seedling and a lower dose in combination with delayed treatment resulted in the highest internal ethylene concentration and lowest firmness in Cox's Orange Pippin (Johnson 2008).

Delaying application can also affect response. In Pink Lady 1-MCP at 0.5 µl L⁻¹ at 20 °C for 24 h significantly inhibited respiration rate, ethylene production and ACC oxidase activity, while it slowed down the decrease in flesh firmness and TA of fruits

during storage at 0 °C (Guo *et al.* 2007). Internal ethylene concentration in Bramley's Seedling apples also tended to be higher where treatment was delayed and fruit was softer. Watkins and Nock (2012) found that treatment of McIntosh and Empire fruit with 1-MCP as soon as possible after harvest meant that storage operators had more freedom to delay CA storage application.

Development of physiological storage disorders has also been associated with 1-MCP treatment. Watkins and Nock (2012) found that its effects on storage disorders were inconsistent, although they detected slight increases in the risk of external CO₂ injury. DeEll *et al.* (2005) reported that 1-MCP resulted in CO₂ injury in McIntosh and Empire apples, and a higher incidences of core browning in Empire and internal browning in Gala. Gala with no 1-MCP in storage at 0 °C for 240 days with zero CO₂ resulted in a large reduction in firmness but Gala in storage in 1% O₂ + 0% CO₂ had similar respiration rates, ethylene and total volatiles production to those fruits stored in 2.5% O₂ + 2% CO₂. Empire stored at 0 °C at 2.5 °C in CA developed large incidences of core browning, which was worse in 1-MCP-treated fruits. Subsequently DeEll and Ehsani-Moghaddam (2012) suggested that delaying CA storage for 1 or 2 months at 1 °C to reduce the development of certain storage disorders in Empire could be utilized in combination with 1-MCP treatment to retard fruit softening during storage at 3 °C with 2.5% O₂ + 2.0% CO₂ for 7–9 months. de Castro *et al.* (2007) found that 1-MCP did not significantly affect flesh browning incidence in Pink Lady. Storage of Braeburn at 1 °C in DCA, which was set at 0.3–0.4% O₂ + 0.7–0.8% CO₂, maintained firmness at levels comparable to 1.5% O₂ + 1.0% CO₂ plus 1-MCP applied at 625 ppb for 24 h at 3.5 °C. Storage was for some 7 months followed by 7 days shelf-life period at 20 °C. DCA plus 1-MCP resulted in no softening during storage, but 1-MCP-treated fruit in both 1.5% O₂ + 1.0% CO₂ and DCA showed a higher incidence of Braeburn browning disorder (on average +53%) than non-treated. DCA storage reduced Braeburn browning disorder to 46% compared to fruit stored only in 1.5% O₂ + 1.0% CO₂. The fruits' susceptibility to low temperature breakdown and external CO₂ injury was significantly higher in DCA than 1.5% O₂ + 1.0% CO₂ or in air (Lafer 2008). Watkins and Miller (2003) showed that 1-MCP could reduce superficial scald incidence

and accumulations of α -farnesene and its putative superficial scald causing catabolite, conjugated triene alcohol during air storage of apples, but that there were differences between cultivar and storage conditions. Rupasinghe *et al.* (2000) also showed that the contents of α -farnesene and conjugated triene alcohol in the skin were reduced 60–98% by 1-MCP and the incidence of superficial scald suppressed by 30% in McIntosh and by 90% in Delicious apples. Pink Lady exposed to 1 μ L L⁻¹ 1-MCP for 24 h did not significantly affect flesh browning incidence during storage at 0.5 °C, while delaying CA by 2 or 4 weeks reduced it (de Castro *et al.* 2007). 1-MCP prevented scald in Cortland in 1 year and reduced it to 5% or less in another year when fruits were stored for 120 days and to 34% or less after 200 days of storage (Moran 2006). Fruit stored at 20 °C longer than 40 days showed some shrivelling and decay, regardless of 1-MCP treatment (Argenta *et al.* 2001).

1-MCP has been shown to have beneficial effects on the storage of apples. However, Watkins and Nock (2004) pointed out that its response can vary with the cultivar as well as harvest maturity, handling practices, time between harvest and treatment and type and duration of storage. On the negative side they found that 1-MCP might increase susceptibility to chilling injury, CO₂ injury and superficial scald. The protocol recommended by Johnson (2008) for apples grown in the United Kingdom was 625 nL L⁻¹ of 1-MCP (based on empty store volume) applied for 24 h with minimal delay between harvest and application. He reported that differences in firmness between air- and CA-stored Cox's Orange Pippin increased with time in store because of the more rapid softening of air-stored fruit. Only 5% CO₂ + 1% O₂ storage gave complete control of scald in 1-MCP-treated Bramley's Seedling apples stored for long periods. Delaying establishment of CA conditions from 10 to 28 days to avoid CO₂ injury in Bramley's Seedling did not affect internal ethylene concentration, scald incidence or firmness in 2002 but in 2003 there was an adverse effect of a 21-day delay on the firmness of fruit stored in 5% CO₂ + 1% O₂ for 284 days but no effects on scald development. Fiesta, Jonagold, Idared and Braeburn treated with 1-MCP failed to soften during 90 days of CA storage. Despite a reduced internal ethylene concentration Meridian apples treated with 1-MCP were not significantly firmer than non-treated, and Spartan did

not respond to 1-MCP either in terms of internal ethylene concentration or firmness.

Aminoethoxyvinylglycine

Ethylene synthesis in plant material can be inhibited by aminoethoxyvinylglycine (AVG), which is sold commercially e.g. ReTain[®] and is used in apple orchard sprays. Its mode of action is to inhibit the activity of ACC-synthase. AVG treatment delayed the onset of the climacteric in McIntosh apples during storage but did not reduce internal ethylene concentration (Robinson *et al.* 2006). Johnson and Colgan (2003) showed that Queen Cox apples, which had been sprayed with 123.5 g AVG ha⁻¹ before harvest, were firmer than those that had not been sprayed after 6 months of storage at 3.5 °C in ethylene-free 1.2% O₂ + 98.8% N₂. The additive effect on firmness of AVG treatment and ethylene removal was negated by the development of core flush and after a simulated marketing period 57% of fruits were affected after this combination of treatments. Drake *et al.* (2006) found that AVG reduced starch loss and ethylene production, retained firmness and reduced cracking in Gale apples, but reduced the sensory acceptance of apples and apple juice. AVG followed by ethylene treatment (Ethaphon) reduced starch loss, ethylene production and cracking and maintained firmness. This combination also improved the sensory acceptance of apples but reduced sensory preference of apple juice. Harb *et al.* (2008b) showed that the biosynthesis of volatiles is highly reduced in apples after treatments with AVG especially after an extended storage periods in ULO. They found that after storage at 3.5 °C in 1.2 % O₂ + less than 1 % CO₂, with no removal of ethylene, until late March or early April treating AVG-treated fruit with alcohols and aldehydes led to a marked increase in the production of the corresponding volatiles. However, this effect was transitory in both AVG-treated fruits and those stored in ULO. Whale *et al.* (2008) reported that Cripp's Pink sprayed with AVG 5 weeks before harvest had retarded colour development at harvest, but Ethephon applied after AVG enhanced percentage red blush, anthocyanin concentration and reduced chlorophyll concentration in the fruit. They concluded that the combination of AVG and Ethephon was effective in improving colour of Cripp's Pink apples at commercial harvest without adversely affecting other fruit quality attributes.

Packhouses

Since apples are a high-value crop sophisticated pack-houses and packing equipment has been developed. Finney (1970) discussed grading apples on the basis of firmness and much work has taken place since then and it is still not used in commercial packhouses. Clarke (1996) described a size-grading machine where there are two cables along which the crop runs are made up from high tensile, polyethylene-coated steel. When the crop reaches the prescribed point, ejector bars controlled by solenoid valves and operated by compressed air cylinders push it into the chute. The machine is very gentle to the crop, and high drops are unnecessary although padded chutes can be provided.

Chen *et al.* (1992) discussed vibrational techniques for grading fruit and identified many of the factors that influence the acoustic responses of apples. It is however difficult to test the fruit without any physical contact. The main approach was to impart a band of frequencies into the fruit by a contacting emitter and then to pick up the transmitted signal frequencies using a detector that rests briefly on the surface of the fruit. This would most commonly be a piezoelectric surface or an accelerometer. Rapid analysis of the acoustic resonance signal by fast Fourier transform means that the whole sorting process can be carried out fairly rapidly but not yet at commercially attractive rates for most fruits. Experimental machines do exist however which often take up to 1 s per fruit, which is too long (Kouno *et al.* 1993a, 1993b, 1993c).

Fruit coatings

Coating fruit with Tal Prolong (Bancroft 1989), Semperfresh (Kerbel *et al.* 1989) or chitosan (Davies *et al.* 1988) has been shown to delay postharvest deterioration of apples. Supapvanich *et al.* (2012) found that coating fruit with konjac glucomannan incorporated with pineapple core extract was effective in retarding browning, enhancing total phenols, inhibiting both PPO and POD activities and reducing weight loss of fresh-cut fruit of the cultivar Taaptimjaan Rose during refrigerated storage. Glucomannan is a water-soluble polysaccharide that is used as an emulsifier and thickener in foods. It is a hemicellulose component in the cell walls of some plants including *Amorphophallus konjac*.

Table 52 Effects of precooling method on the half-cooling time of apples packed loosely in 18 kg boxes (source: adapted from Hall 1972)

Cooling method	Half cooling time
Conventional cool room	12 h
Tunnel with air velocity of 200–400 m min ⁻¹	4 h
Jet cooling with air velocity of 740 m min ⁻¹	45 min
Hydrocooling (loose fruit)	20 min

Precooling

Precooling is not a common commercial practice with apples, but there is some information in the literature, which gives different recommendations. MAFF (n.d.) found that placing the fruit in a conventional cold storage was the most acceptable, but force air-cooling with high humidity was suitable and hydrocooling less suitable and vacuum cooling unsuitable. However, hydrocooling was reported to be most effective (Table 52) since it rapidly cooled the fruit and had no detrimental effects on their quality.

Postharvest physiology

Ethylene

Apple is a climacteric fruit and is sensitive to exposure to ethylene. In Cox's Orange Pippin apples stored at 3.3 °C softening was hastened with ethylene levels of 1 µl L⁻¹ in the store (Knee 1976). However, Stow (1989a) showed that lowering the ethylene concentration in the containers in which the fruit were stored reduced the ethylene concentration in the core of apples. Ethylene concentrations in the core of apples were generally progressively lower with reduced O₂ concentrations in the store over the range of 0.5–2% O₂ (Stow 1989b).

Texture

Landfald (1966) showed that fruit softened during storage even at 0 °C (Table 53). Stow and Genge (1993) suggested that softening resulted from loss of cell-to-cell cohesion. Dover and Stow (1993) found that the major effect of ethylene removal from stored apples is to delay in the onset of softening and that removal of ethylene from the store could slow the rate of softening once it has started.

Flavour and aroma

These are related to organic volatiles. An experiment measured organic volatile production of Golden

Table 53 Effects of temperature and duration of storage on the firmness of apples in kilogram per square centimetre (initial value 9.2). Results are the means of three cultivars (source: adapted from Landfald 1966)

Days in storage	Temperature (°C)			
	0	4	8	12
30	8.9	7.6	6.6	6.3
60	7.7	6.7	5.9	5.7
90	7.2	6.3	5.7	5.5
120	6.7	5.9	5.5	5.3

Delicious over a 10-day period at 20 °C after removal from the cold store. It was found that aroma volatiles were suppressed during storage at 1 °C for up to 10 months in atmospheres containing 3% CO₂ or 1–3% O₂ compared to storage in air (Brackmann 1989). Yahia (1989) found that in McIntosh and Cortland most organic volatile compounds were produced at lower rates during ripening after controlled atmosphere storage than those produced from fruits ripened immediately after harvest. In experiments on the storage of Filippa, Ingrid Marie and Lobo, Landfald (1966) found that temperature in the range of 4–12 °C did not affect their flavour score, but those that had been stored at 0 °C had an inferior flavour.

Colour

The ground colour of fruits can change during storage (Landfald 1966), which is mainly due to the breakdown of chlorophyll (Table 54).

Simple stores

In Britain and many other European countries before refrigeration storage was developed, cellars were traditionally used for storage during the winter.

Table 54 Effects of temperature and duration of storage on the ground colour score (0–10) of apples. Results are the means of three cultivars (source: adapted from Landfald 1966)

Days in storage	Temperature (°C)			
	0	4	8	12
30	2.3	3.1	4.5	6.5
60	2.8	4.3	6.3	8.4
90	3.7	5.1	7.8	9.5
120	4.0	5.3	8.3	9.7

The apples were usually spread out thinly on shelves to ensure good air circulation. In the mountainous regions of Nepal caves are dug into the sides of slopes for storing apples with a wooden door. The doors may be left open at night to ensure the temperature in the store remains low. In such a climate the humidity is often low which can lead to desiccation of the fruit. To relieve this, the floor of the store can be kept wet (Thompson 1978a).

Chilling injury

Some cultivars suffer from chilling injury at temperatures above 0 °C; also the environment in which they are grown can affect susceptibility. Symptoms include a brown discoloration of the cortex with streaks of darker brown in the vascular region and the tissue remaining moist. In Ellison's Orange and some other cultivars symptoms can take the form of ribbon-shaped brown patches on the skin and extending 2–3 mm into the cortex, often called ribbon scald (Wilkinson 1972).

Storage and controlled atmosphere storage conditions

CA storage is very effective in prolonging their postharvest life. Their rate of ethylene production was shown to be about half in an atmosphere of 2.5% O₂ compared to fruit stored in air (Burg and Burg 1962). Ethylene biosynthesis was shown to be affected by CO₂ levels in store. Increased levels of CO₂ reduced ethylene levels in controlled atmosphere stores containing apples (Tomkins and Meigh 1968). In a large commercial store in United Kingdom they use 3.5 °C with 1% CO₂ and 1.2% O₂ for Cox's Orange Pippin. To achieve this, the store is sealed directly after loading is completed, and the temperature is reduced as quickly as possible. When it is below 5 °C nitrogen is injected to reduce the oxygen level to about 3%. The O₂ level is allowed to decline to about 2% for 7 days through fruit respiration and then progressively to 1.2% over the next 7 days. Bramley Seedling apples were treated in a similar way with the final conditions being 3.5–4 °C with 5% CO₂ and 1% O₂ (East Kent Packers Limited 1994, personal communication, they have

subsequently closed down). General recommended storage conditions that were not specific to a particular cultivar were given as 0–1 °C with 1–2% CO₂ and 2–3% O₂ (Kader 1985). Kader (1992) revised these recommendations to 0–1 °C with 1–5% CO₂ with 1–3% O₂. Another general recommendation was given by SeaLand (1991) as –1.1 °C and 90–95% r.h. for 90–240 days for non-chilling, sensitive fruit and 4.4 °C and 90–95% r.h. for 40–45 days for chilling, sensitive fruit. Storage temperature is very important as it affects the maximum time the apples can be stored. This includes chilling injury and senescent breakdown. Fruit colour and firmness were also affected by storage temperature (Table 54a and b). Tu *et al.* (2000) studied the effects of humidity on the quality of Braeburn and Jonagold apples during marketing at 20 °C. They found that at 95% r.h. they retained their firmness but there was an increase in mealiness, reduced tensile strength and an increase of cell separation compared to those at held in 30 or 65% r.h. Specific storage recommendations for major cultivars are given below.

Allington pippin

Fidler (1970) recommended 3–3.5 °C with 3% CO₂ and 3% O₂.

Aroma

Storage trials of Aroma apples at 2 °C and 88% r.h. in air, or 2% O₂ with 2% CO₂ or 3% O₂ with 3% CO₂ for 115, 142 and 169 days were described by Haffner (1993). One set of samples analysed immediately and a second set of samples analysed after 1 week in a cold store and a third set after 1 week in a cold store followed by 1 week in ambient conditions of 18–20 °C and 25–30% r.h. to simulate shelf life. Weight loss was 0.6% per month for controlled atmosphere storage compared to 1.5% in cold storage. Controlled atmosphere storage controlled *Gloeosporium album* [*Pezizicula alba*] and *G. perennans* [*P. malicorticis*]. Fruits undergoing simulated shelf life experiments showed a severe loss in quality after storage with damage from *Gloeosporium* rot, wilting and over-ripeness. Controlled atmosphere storage delayed the maturity process, controlled the weight loss and resulted in better eating quality during shelf life.

Boskoop

Meheriuk (1993) recommended 3–5 °C with 0.5–2% CO₂ and 1.2–2.3% O₂ for 5–7 months. Koelet (1992) advocated 3–3.5 °C with 0.5–1.5% CO₂ and 2–2.2% O₂. Hansen (1977) suggested a temperature of not lower than 4 °C with 3% CO₂ and 3% O₂. Schaik (1994) described experiments where fruits of the cultivar Schone van Boskoop (also called Belle de Boskoop) from several orchards were held in controlled atmosphere storage with a combined scrubber/separator or with a traditional lime scrubber, in 0.7% CO₂ and 1.2% O₂, at 4.5 °C, followed by holding at 15 °C for 1 week or at 20 °C for 2 weeks. Ethylene concentration during storage with a scrubber/separator rose to only 20 µl L⁻¹, compared to up to 1000 µl L⁻¹ in a cell without a scrubber. The average weight loss, rots (mostly *Gloeosporium* spp.), flesh browning and core flush were also slightly lower in the scrubber/separator cell, but the incidence of bitter pit was slightly greater. Using a scrubber/separator did not affect fruit firmness and colour. For Schone van Boskoop Anonymous 3 (n.d.) recommended 3–5 °C and 90–95% r.h. for 3½ months in air and 7 months in ULO conditions of 2 weeks cooling in air then 1.6% O₂ + less than 1% CO₂. It is very susceptible to a series of storage deficiencies that can be inhibited by ULO. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	3–3½	<1	2–2.2
Denmark	3½	1.5–2	3–3.5
France	3–5	0.5–0.8	1.5
Germany (Saxony)	3	1.1–1.3	1.3–1.5
Germany (Westphalia)	4–5	2	2
Holland	4–5	much <1	1.2
Switzerland	4	2–3	2–3

Bowden's seedling

Fidler (1970) recommended 3.5 °C with 5% CO₂ and 3% O₂.

Braeburn

Brackmann and Waclawovsky (2000) recommended 0 °C and 96% r.h. with 1% O₂ and 3% CO₂ for 8 months plus 7 days at 31 °C shelf life with no

physiological disorders. However, greater than 1.5% CO₂, with less than 1.5% O₂ could result in a higher incidence of flesh and core browning (Rabus and Streif 2000). In Canada storage at 0 °C in 1.2 or 1.5% O₂ with 1.0 or 1.2% CO₂ retained firmness and acidity better than storage in air, but fruit had more core browning and superficial scald (Lau and Yastremski 1993, Elgar *et al.* 1998). Growing conditions were shown to influence these disorders so following a cool growing season it was recommended that Braeburn be harvested at starch index values between 2.5 and 3.0 (0–9 scale) and stored in air storage at 0 °C to avoid the risks of scald, browning disorder and internal cavities. The fruits could be stored in less than 1% CO₂ (preferably close to 0.1%) and greater than 1.5% O₂ after warm seasons (Lau and Yastremski 1993). Clark and Burmeister (1999) found that during storage at 0.5 °C, with 2% O₂ and 7% CO₂ there was 1.5% brown tissue after 2 weeks, increasing to 15.9 and 21.3% after 3 and 4 weeks, respectively. It was suggested that they should be stored at for 2 weeks in air followed by 1% CO₂ and 3% O₂ all at 0 °C (Elgar *et al.* 1998). This is because they found that browning disorder appeared to develop during the first 2 weeks of storage, and storage in air at 0 °C prior to controlled atmosphere storage decreased incidence and severity of the disorder. Development of browning induced in Braeburn fruits by a damaging CO₂ concentration could be detected with magnetic resonance imaging (Clark and Burmeister 1999). Lee *et al.* (2012b) used 0.5 °C with 1.5% O₂ with 3% CO₂. Anonymous 3 (n.d.) recommended 0.5–3 °C and 90–95% r.h. with 1.5% O₂ + 1% CO₂ after cooling for 3 weeks. It was also reported that they can be stored for long periods at a low temperature and were sensitive to storage deficiencies that can be inhibited by ULO where they can be stored for 6–9 months.

Bramley's seedling

Fidler and Mann (1972) recommended 3–4 °C with 8–10% CO₂ and about 11–13% O₂. Wilkinson and Sharples (1973) recommended 3.3–4.4 °C with 8–10% CO₂ and no scrubber for 8 months. Sharples and Stow (1986) recommended 4–4.5 °C with 8–10% CO₂ where no scrubber is used and 4–4.5 °C with 6% CO₂ and 2% O₂ where a scrubber is used. The following conditions were said to be

used in their commercial controlled atmosphere stores by East Kent Packers Limited: 3.5–4 °C with 5% CO₂ and 1% O₂ (East Kent Packers Limited 1994, personal communication). Johnson (1994, personal communication 1997) recommended the following:

Temperature (°C)	CO ₂ (%)	O ₂ (%)	Storage time in weeks
4–4.5	8–10	11–13	39
4–4.5	6	2	39
4–4.5	5	1	44

Bravo de Esmolfe

Manoso and Nunes (2012) isolated yeasts from the surface of Bravo de Esmolfe fruit cultivated in north Portugal and found that the most effective in controlling diseases was *Metschnikowia andauensis*, strain NCYC 3728 (PBC-2). In semi-commercial trials in cold storage, the reduction of blue mould *Penicillium expansum* was 90%. Rapid colonization of fresh apple fruit wounds was observed during the first 24 h of cold storage, followed by a significant population increase during the first 15 days of storage and then the population remained stable until the end of storage.

Cacanska Pozna

Jankovic and Drobnjak (1992, 1994) stored Cacanska Pozna at 1 °C and 85–90% r.h., either in a controlled atmosphere (7% CO₂ with 7% O₂) or under normal atmospheric conditions. Weight losses and decay were negligible in controlled atmospheres (0–0.78%). Fruits stored in controlled atmosphere stores exhibited no physiological disorders.

Charles Ross

Fidler (1970) recommended 3.5 °C with 5% CO₂ and 3% O₂. Sharples and Stow (1986) recommended 3.5–4 °C and 5% CO₂ for fruit stored without a scrubber and 5% CO₂ with 3% O₂ for those stored with a scrubber.

Chieft

Naeve and Domoto (2008) recommended –1.1–0 °C and 90–95% r.h. for 3–6 months.

Cortland

Naeve and Domoto (2008) recommended –1.1–0 °C and 90–95% r.h. for 3–4 months. Anonymous (1968)

recommended 3.3 °C with 2% then 5% CO₂ and 3% O₂ for 5–6 months. Meheriuk (1993) recommended 0–3 °C with 5% CO₂ and 2–3.5% O₂ for 4–6 months. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Canada (Nova Scotia)	3	4.5	2.5
Canada (Nova Scotia)	3	1.5	1.5
Canada (Quebec)	3	5	2.5–3
USA (Mass.)	0	5	3

Cox's Orange Pippin

Fidler and Mann (1972) and Wilkinson and Sharples (1973) recommended 3.3–3.9 °C with 5% CO₂ and 3% O₂ for 5 months, but where core flush is a problem then 0–1% CO₂ with 1.8–2.5% O₂ for 6 months was recommended. Stoll (1972) suggested 4 °C with 1–2% CO₂ and 3% O₂. Sharples and Stow (1986) advocated 3.5–4 °C with 5% CO₂ where no scrubber is used and 3.5–4 °C with 5% CO₂ and 3% O₂ (for storage to mid-February), less than 1% CO₂ with 2% O₂ (for storage to late March), less than 1% CO₂ with 1.25% O₂ (for storage to late April) and less than 1% CO₂ with 1% O₂ (for storage to early May) where a scrubber is used. East Kent Packers Limited used 3.5 °C with 1% CO₂ and 1.2% O₂ for Cox's Orange Pippin in their commercial stores (East Kent Packers Limited 1994, personal communication). Koelet (1992) recommended 3–3.5 °C with 0.5–1.5% CO₂ and 2–2.2% O₂. Meheriuk (1993) recommended 3–4.5 °C with much less than 1–2% CO₂ (*sic*) and 1–3.5% O₂ for 5–6 months. Johnson (1994, personal communication 1997) recommended the following:

Temperature (°C)	CO ₂ (%)	O ₂ (%)	Storage time in weeks
3.5–4	5	3	20
3.5–4	<1	2	23
3.5–4	<1	1.2	28
3.5–4	<1	1	30

Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	3–3.5	<1	2–2.2
Denmark	3.5	1.5–2	2.5–3.5
England	4–4.5	<1	1.25
France	3–4	<1	1.2–1.5
Germany (Saxony)	3	1.7–1.9	1.3–1.5
Germany (Westphalia)	4	2	1–2
Holland	4	much <1	1.2
New Zealand	3	2	2
Switzerland	4	2–3	2–3

Crispin

Sharples and Stow (1986) recommended 3.5–4 °C with 8% CO₂ where no scrubber is used, but that there was a risk of the physiological disorder of core flush at 8% CO₂.

Delicious

See also the sections on Red Delicious, Starking and Golden Delicious. Drake (1993) described the effects of a 10-day delay in harvesting date and/or a 5-, 10- or 15-day delay in the start of controlled atmosphere storage (1% O₂ and 1% CO₂) on Delicious fruits (Bisbee, Red Chief and Oregon Spur strains). Delayed harvest increased red colour of the skin at harvest in Bisbee and Red Chief, but not Oregon Spur; soluble solids content and size also increased, but up to 12% of firmness was lost, depending on strain. Immediate establishment of controlled atmosphere conditions after harvest resulted in good quality fruits after 9 months of storage, but reduced quality was evident when controlled atmosphere establishment was delayed by 5 days (the interim period being spent in refrigerated storage at 1 °C). Longer delays did not result in greater quality loss. Oregon Spur had a redder colour at harvest and after storage than the other two strains. Sensory panel profiles were unable to distinguish between strains, harvest dates or delays in the time of controlled atmosphere establishment. Mattheis *et al.* (1991) stored Delicious fruit in 0.5% O₂ plus 0.2% CO₂ at 1 °C for 30 days and found that they developed high concentrations of ethanol and acetaldehyde. Scald susceptibility in Delicious apples was found to be strain-dependent. While storage in 0.7% O₂ effectively reduced scald in Starking and Harrold Red fruits picked over a wide range of maturity stages, it did not adequately reduce scald in Starkrimson fruits after 8 months of storage (Lau and Yastremski 1993).

Discovery

Discovery has been reported to have poor storage qualities, and Sharples and Stow (1986) recommended 3–3.5 °C with less than 1% CO₂ and 2% O₂ for 7 weeks.

Edward VII

Fidler (1970) recommended 3.5–4 °C with 8–10% CO₂ with information supplied only for stores with no scrubber, and Wilkinson and Sharples (1973) recommended 3.3–4.4 °C with 8–10% CO₂ and no scrubber for 8 months. Sharples and Stow (1986) also recommended 3.5–4 °C and 8% CO₂ for fruit stored without a scrubber.

Egremont Russet

Wilkinson and Sharples (1973) recommended 3.3 °C with 5% CO₂ and 3% O₂ for 5 months. Fidler (1970) recommended 3.3–4.4 °C with 7–8% CO₂ with information supplied only for stores with no scrubber.

Ellison's Orange

Fidler (1970) and Sharples and Stow (1986) recommended 4–4.5 °C and 5% CO₂ with 3% O₂ for fruit stored with a scrubber or less than 1% CO₂ with 2% O₂.

Elstar

Sharples and Stow (1986) recommended 1–1.5 °C and less than 1% CO₂ with 2% O₂ for those stored with a scrubber. Meheriuk (1993) recommended 1–3 °C with 1–3% CO₂ and 1.2–3.5% O₂ for 5–6 months. In a trial with Elstar apples stored in 1 or 3% O₂, the ethylene concentration in the lower O₂ concentration remained less than 1 µl L⁻¹ after 8 months. After holding at 20 °C for 1 week fruit firmness declined only slightly, and taste was considered good. In the higher O₂ concentration, however, the ethylene concentration rose rapidly to almost 100 µl L⁻¹ and fruit hardness declined markedly after holding at 20 °C (Schaik 1994). Elstar fruits were stored in controlled atmospheres of 1 or 5% O₂ + 0.5% CO₂, or 3% O₂ + 0.5 or 3.0% CO₂ at 1.5 °C. An ethylene scrubber was used continuously in the low-ethylene cabinets and at intervals in other cabinets to remove excess ethylene produced by the fruits. Fruit firmness was measured 1 week after removal from storage and holding at 20 °C. Low O₂ concentrations in

addition to low temperature further decreased ethylene sensitivity in apples. Increased CO₂ concentrations did not affect fruit firmness when fruits were stored under low ethylene but were clearly beneficial when ethylene was present in the storage atmosphere (Woltering *et al.* 1994). Schouten (1997) compared storage at 1–2 °C in either 2.5% CO₂ with 1.2% O₂ or less than 0.5% CO₂ with 0.3–0.7% O₂. The fruit stored in 0.5% CO₂ with 0.3–0.7% O₂ were shown to be of better quality both directly after storage and after a 10-day shelf life period in air at 18 °C. Anonymous 3 (n.d.) reported that Elstar was very tolerant to extremely low O₂ levels and not very susceptible to storage deficiencies. Recommended storage conditions were 0–4 °C and 90–95% r.h. for 3 months in air, 7 months in ULO and 8 months in DCA. Recommended CA conditions were 1 month in 1.3% O₂ + 1–2.5% CO₂ then 1–1.2% O₂ + 2.5% CO₂ or DCA. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	1	2	2
Canada (Nova Scotia)	0	4.5	2.5
Canada (Nova Scotia)	0	1.5	1.5
Denmark	2–3	2.5–3	3–3.5
England	1–1.5	<1	2
France	1	1–2	1.5
Germany (Saxony)	2	1.7–1.9	1.3–1.5
Germany (Westphalia)	2–3	3	2
Holland	1–2	2.5	1.2
Slovenia	1	3	1.5

Empire

Meheriuk (1993) recommended 0–2 °C with 1–2.5% CO₂ and 1–2.5% O₂ for 5–7 months. Lee *et al.* (2012b) reported that in storage at 2–3 °C 1-MCP enhanced flesh browning but in their trials in 2% O₂ + 2% CO₂ at either 0.5 °C or 3.3 °C for up to 40 weeks, no consistent patterns of change in flesh browning were detected. They could not find a direct role of antioxidant metabolism during development of flesh browning in Empire. Herregods (1993) and

Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Canada (British Columbia)	0	1.5	1.5
Canada (Ontario)	0	2.5	2.5
Canada (Ontario)	0	1	1
USA (Michigan)	0	3	1.5
USA (New York)	0	2–2.5	1.8–2
USA (Pennsylvania)	–0.5 to +0.5	0–2.5	1.3–1.5

Fiesta

Sharples and Stow (1986) recommended 1–1.5 °C and less than 1% CO₂ with 2% O₂ for those stored with a scrubber.

Fortune

Fidler (1970) recommended 3.5–4 °C with 7–8% CO₂ for stores with no scrubber or either 5% CO₂ and 3% O₂ or less than 1% CO₂ and 2% O₂ for stores fitted with a scrubber.

Fuji

Meheriuk (1993) recommended 0–2 °C with 0.7–2% CO₂ and 1–2.5% O₂ for 7–8 months. Fuji apples were stored at 0 °C in a controlled atmosphere (1.5% O₂, with <0.5% CO₂). Fruits were removed from cold storage after 3, 5, 7 and 9 months and assessed for storage life and sensory acceptability on return to air at 20 °C after 0, 4, 11, 18 and 25 days. Harvest maturity was not critical for Fuji apples, which maintained a good level of consumer acceptability for up to 9 months in storage and 25 days at 20 °C in air (Jobling *et al.* 1993). Work in Australia showed that fruits store well in 2% O₂ and 1% CO₂ at 0 °C (Tugwell and Chvyl 1995). Anonymous 3 (n.d.) recommended 0–1 °C and 90–95% r.h. for 1–7 months or CA in 1–2.5% O₂ + 1–2.5% CO₂ for 8–11 months in ULO. Fuji is quite tolerant to very low O₂ conditions but if it is harvested late, it cannot be stored in high CO₂ as it may go brown on the inside at 0.5%. Jobling (2002a) reported that the postharvest life of Fuji was compromised if stored at 3 °C rather than 0 °C. Herregods (1993) and Meheriuk (1993) summarized

general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (south)	0	1	2
Australia (Victoria)	0	2	2–2.5
Brazil	1.5–2	0.7–1.2	1.5–2
France	0–1	1–2	2–2.5
Japan	0	1	2
USA (Washington)	0	1–2	1–2

Fuji Kiku-8

Ortiz *et al.* (2012) showed that spraying trees with calcium improved their firmness retention during storage. They applied seven weekly pre-harvest sprays of 1.6% w/v calcium 81–123 days after full bloom. Treated fruit had improved postharvest cell-to-cell adhesion of fruit as indicated by better preservation of the middle lamella and by higher contents of ionically bound pectins. Matrix glycan breakdown was also delayed in response to calcium treatment. Calcium applications partially suppressed pectinmethylesterase, pectate lyase, β -galactosidase, α -l-arabinofuranosidase and β -xylosidase activities, without any apparent relationship with ethylene production rates.

Gala

Gala were stored at 0 °C in 1.5% O₂ with less than 0.5% CO₂ for up to 9 months (Jobling *et al.* 1993). Johnson (1994) recommended 3.5–4 °C in less than 1% CO₂ with 2% O₂ for 23 weeks. However, more recent work has shown that Gala grown in the United Kingdom can be stored at 1.5 °C in O₂ concentrations as low as 1% with CO₂ concentrations of 2.5–5% (Stow 1996a). Meheriuk (1993) recommended –0.5 to 3 °C with 1–5% CO₂ and 1–2.5% O₂ for 5–6 months. Anonymous 3 (n.d.) recommended 0–2 °C and 90–95% r.h. for 3½ months or CA in 1.2% O₂ + 2% CO₂ for 6½ months. They also reported that Gala was quite sensitive to Scald but this problem was significantly reduced in ULO storage. Su *et al.* (2012) showed that hydrogen peroxide was associated

with efficient wound healing in Gala fruit but wound healing ability declined with fruit ripening. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (south)	0	1	2
Australia (Victoria)	0	1	1.5–2
Brazil	1–2	2.5–3	1.6–2
Canada (British Columbia)	0	1.5	1.2
Canada (Nova Scotia)	0	4.5	2.5
Canada (Nova Scotia)	0	1.5	1.5
Canada (Ontario)	0	2.5	2.5
France	0–2	1.5–2	1–2
Germany (Westphalia)	1–2	3–5	1–2
Holland	1	1	1.2
Israel	0	2	0.8–1
New Zealand	0.5	2	2
South Africa	–0.5	2	2
Switzerland	0	2	2
USA (Washington)	0	1–2	1–2

Gloster

Sharples and Stow (1986) recommended for Gloster 69, 1.5–2 °C with less than 1% CO₂ and 2% O₂. Hansen (1977) advocated 0–1 °C with 3% CO₂ and 2.5% O₂. Meheriuk (1993) suggested 0.5–2 °C with 1–3% CO₂ and 1–3% O₂ for 6–8 months. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	0.8	2	2
Canada (Nova Scotia)	0	4.5	2.5
Canada (Nova Scotia)	0	1.5	1.5
Denmark	0	2.5–3	3–3.5
France	1–2	1–1.5	1.5
Germany (Saxony)	2	1.7–1.9	1.3–1.5
Germany (Westphalia)	1–2	2	2
Holland	1	3	1.2
Slovenia	1	3	1
Slovenia	1	3	3
Spain	0.5	2	3
Switzerland	2–4	3–4	2–3

Golden Delicious

Naeve and Domoto (2008) recommended -1.1 to 0°C and 90–95% r.h. for 3–5 months. Stoll (1972) recommended 2.5°C with 5% CO_2 and 3% O_2 . Koelet (1992) recommended 0.5 – 1°C with 1–3% CO_2 and 2–2.2% O_2 . Meheriuk (1993) recommended -0.5 to 2°C with 1.5–4% CO_2 and 1–2.5% O_2 for 8–10 months. Golden Delicious were stored at 3% CO_2 with 21% O_2 , 3% CO_2 with 3% O_2 , 3% CO_2 with 1% O_2 , 1% CO_2 with 3% O_2 , 1% CO_2 with 1% O_2 and 1% CO_2 with 21% O_2 . All controlled atmosphere storage combinations suppressed volatile production except for fruits stored in 1% CO_2 with 3% O_2 in which volatile production was high (Harb *et al.* 1994). The effect of ultra low O_2 (3% CO_2 with 1% O_2) and low ethylene ($1\ \mu\text{L L}^{-1}\ \text{C}_2\text{H}_4$) storage on the production of ethylene, CO_2 , volatile aroma compounds and fatty acids of Golden Delicious apples harvested at preclimacteric and climacteric stages was evaluated during 8 months of storage and during the following 10 days at 20°C in air. 1-aminocyclopropane 1-carboxylic acid oxidase activity, increase in ethylene and CO_2 and production of aroma volatiles and fatty acids were lower during the 10 days after storage following ultra low O_2 storage than following non-controlled atmosphere, cold storage. The reduction of all these parameters was more pronounced in fruits harvested at the preclimacteric stage than in those harvested when climacteric. Increasing CO_2 concentrations from 1 to 3% under ultra low O_2 conditions (1% O_2) intensified the inhibition of respiration and the production of ethylene, aroma and fatty acids. On the other hand, removal of ethylene from the store atmosphere only slightly affected CO_2 and aroma production by apples (Brackmann *et al.* 1995). Van der Merwe (1996) recommended -0.5°C and 1.5% CO_2 with 1.5% O_2 for 9 months. Sharples and Stow (1986) recommended 1.5 – 3.5°C with 5% CO_2 and 3% O_2 . Anonymous 3 (n.d.) recommended 0 – 4°C and 90–95% r.h. for 3 months in air and 10 months in ULO or DCA with the first month in 1.3% O_2 + 4% CO_2 then 1–1.2% O_2 + 4% CO_2 . It was also reported that it is quite tolerant to very low O_2 levels and quite tolerant of high CO_2 and is quite sensitive to Scald, which was significantly reduced in ULO storage.

In experiments conducted over 4 years at 1% O_2 with 1% CO_2 or 1% O_2 with 6% CO_2 , fruit rot, scald and flesh browning were prevented to a large extent (Strempl *et al.* 1991). Starking Delicious and Golden

Delicious can be stored for up to 9 months without appreciable loss of quality at 0°C in 3% CO_2 with 3% O_2 (Ertan *et al.* 1992).

Golden Delicious in storage at 0°C had a threshold for peel injury at 15% CO_2 with 3% O_2 , with little difference between 3 and 5% O_2 levels at 20% CO_2 . The development of superficial scald (which did not occur at 3% O_2) diminished at 15% O_2 with increasing CO_2 and was completely inhibited by 20% CO_2 . Fruit softening was inhibited with increasing CO_2 levels in a similar manner at both 3 and 5% O_2 levels, even though the higher O_2 level enhanced softening. No softening occurred at 20% CO_2 regardless of O_2 level both during storage and subsequent ripening. This could be related to the total inhibition of ethylene evolution, which occurred at 20% CO_2 at both O_2 levels. Reducing the O_2 level predominantly inhibited chlorophyll degradation. TA was highest when CO_2 was increased to 10% at 15% O_2 and to 5% at 3% O_2 (Ben Arie *et al.* 1993). At 1°C CA storage suppressed aroma production compared to fruit stored in air with the greatest reduction in 1% O_2 and 3% CO_2 . A partial recovery of aroma production was observed when CA-stored fruits were subsequently stored for 14 days in air at 1°C (Brackmann *et al.* 1993). Anonymous (1968) recommended -1.1 to 0°C with 1–2% CO_2 and 2–3% O_2 . de Wild (2001) recommended 1°C with 1.2% O_2 and 4% CO_2 . Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature ($^{\circ}\text{C}$)	CO_2 (%)	O_2 (%)
Australia (south)	0	2	2
Australia (Victoria)	0	1	1.5
Australia (Victoria)	0	5	2
Belgium	0.5	2	2
Brazil	1–1.5	3–4.5	1.5–2.5
Canada (British Columbia)	0	1.5	1–1.2
Canada (Ontario)	0	2.5	2.5
China	5	4–8	2–4
France	0–2	2–3	1–1.5
Germany (Saxony)	2	1.7–1.9	1.3–1.5
Germany (Westphalia)	1–2	3–5	1–2
Holland	1	4	1.2
Israel	–0.5	2	1–1.5
Italy	0.5	2	1.5
Slovenia	1	3	1
Slovenia	0	3	1
South Africa	–0.5	1.5	1.5
Spain	0.5	2–4	3

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Switzerland	2	5	2–3
Switzerland	2	4	2–3
USA (New York)	0	2–3	1.8–2
USA (New York)	0	2–3	1.5
USA (Penn.)	–0.5 to +0.5	0–0.3	1.3–2.3
USA (Washington)	1	<3	1–1.5

Storing Golden Delicious infested with eggs of *Rhagoletis pomonella* in 100% nitrogen atmospheres at 20 ± 1 °C resulted in 100% mortality after 8 days but apples developed detectable off-flavour and it was suggested that the treatment might be useful for cultivars less susceptible to anoxia (Ali Niaze *et al.* 1989).

Granny Smith

Meheriuk (1993) recommended –0.5 to 2 °C with 0.8–5% CO₂ and 0.8–2.5% O₂ for 8–10 months. Van der Merwe (1996) suggested –0.5 °C and 0–1% CO₂ with 1.5% O₂ for 7 months. Granny Smith apples were stored at –0.5° for 6 months in normal atmosphere, for 9 months in 1.5% O₂ and 0% CO₂. After storage the fruits were ripened at 20 °C for 7 days before evaluation for superficial scald. In a normal atmosphere, all control fruits developed scald. In controlled atmosphere storage only a few apples developed scald (Van Eeden *et al.* 1992). Anonymous 3 (n.d.) recommended –0.5 to 2 °C and 90–95% r.h. for 1–6 months in air and 7–11 months in 1% O₂ + 1% CO₂. It was reported to be not very sensitive to storage deficiencies but Scald was a problem that can be resolved with ULO storage.

In South Tyrol, Italy controlled atmosphere storage using ultra low O₂ regimes (0.9–1.1% O₂) compared to conventional levels of 2.5–3.0% O₂ controlled scald on Granny Smith fruits for about 150 days. No accumulated alcoholic flavour or any external or internal visual symptoms of low O₂ injury, either during or after storage, were observed (Nardin and Sass 1994).

Granny Smith apples that were kept at 46 °C for 12 h, 42 °C for 24 h, or 38 °C for 72 or 96 h before storage at 0 °C for 8 months in 2–3% O₂ with 5% CO₂ were firmer at the end of storage and had a higher °Brix: acid ratio and a lower incidence of superficial scald than fruits not heat treated. Prestorage regimes of 46 °C for 24 h or 42 °C for 48 h resulted in fruit damage after storage (Klein and Lurie 1992).

After 6.5 months of storage, at –0.5 °C the average percentage of Beurre d'Anjou pears and Granny Smith apples with symptoms of scald ranged from zero in fruits stored in 1.0% O₂ with 0% CO₂ or 1.5% O₂ with 0.5% CO₂ to 2% in fruits stored in 2.5% O₂ with 0.8% CO₂ and 100% in control fruits stored in air (Francile and Battaglia 1992). Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (south)	0	1	2
France	0–2	0.8–1	0.8–1.2
Germany (Westphalia)	1–2	3	1–2
Israel	–0.5	5	1–1.5
Italy	0–2	1–3	2–3
New Zealand	0.5	2	2
Slovenia	1	3	1
South Africa	0–0.5	0–1	1.5
Spain	1	4–5	2.5
USA (Pen.)	–0.5 to +0.5	0–4	1.3–2
USA (Washington)	1	less than 1	1

Honeycrisp

Harb *et al.* (2012) reported that the reason why Honeycrisp apples maintained flesh firmness over extended storage periods was probably associated with restricted cell wall enzyme activity. It did not appear to be related to expression of genes involved in ethylene biosynthesis.

Howgate Wonder

Sharples and Stow (1986) recommended 3–4 °C with 8–10% CO₂ with data only available for controlled atmosphere storage with no scrubbing.

Idared

Idared was stored at 1 °C and 85–90% r.h., either in a controlled atmosphere (7% CO₂, 7% O₂) or under normal atmospheric conditions. Weight loss and decay were negligible in controlled atmospheres (0.0–0.78%). Fruits in controlled atmosphere storage exhibited no physiological disorder (Jankovic and Drobnjak 1992, 1994). Meheriuk (1993) recommended 0–4 °C with less than 1–3% CO₂ and 1–2.5% O₂ for 5–7 months. Hansen (1977) recommended a temperature of not lower than 3 °C with 3% CO₂ and 3% O₂. Sharples and Stow (1986) recommended 3.5–4.5 °C with 5% CO₂ and 3% O₂ or less

than 1% CO₂ and 1.25% O₂ for 37 weeks. In order to maintain fruit at a satisfactory level of firmness Stow (1996b) has suggested storage in 1% O₂ with less than 1% CO₂ for no more than 13 weeks. Holb *et al.* (2012) suggested that integration of preharvest calcium applications and CA storage, together with minimization of fruit injury and infection, may reduce brown rot incidence during long-term storage at 1 °C. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	1	2	2
Canada (Ontario)	0	2.5	2.5
England	3.5–4	8	–
England	3.5–4	<1	1.25
France	2–4	1.8–2.2	1.4–1.6
Germany (Westphalia)	3–4	3	1–2
Slovenia	1	3	3
Spain	2	3	3
Switzerland	4	4	2–3
USA (Michigan)	0	3	1.5
USA (New York)	0	2–3	1.8–2
USA (New York)	0	2–3	1.5
USA (Pen.)	–0.5 to +0.5	0–4	2–3

Ingrid Marie

Fidler (1970) recommended 1.5–3.5 °C with 6–8% CO₂ for stores with no scrubber or less than 1% CO₂ and 3% O₂ for stores fitted with a scrubber. Maxin *et al.* (2012) reported significant reductions in the incidence of fruit rot by dipping them for 3 min at 50–54 °C or rinsing them for 20 or 25 s at 55 °C during storage of up to 100 days at 2 °C followed by 14 days at 18 °C.

James Grieve

Fidler (1970) and Sharples and Stow (1986) recommended 3.5–4 °C with 6% CO₂ and 5% O₂ or less than 1% CO₂ and 3% O₂.

Jonagold

Koelet (1992) recommended, for what he refers to as 'Jonah Gold', 0.5–1 °C with 1–3% CO₂ and 2–2.2% O₂. Meheriuk (1993) recommended 0–2 °C with 1–3% CO₂ and 1–3% O₂ for 5–7 months. In

experiments with Jonagold stored at 5 °C and 95% r.h. for 9 months it was shown that the lower the O₂ concentration is (over the range of 17.0% O₂ with 4.0% CO₂, 1.0% O₂ with 1.0% CO₂ or 0.7% O₂ with 0.7% CO₂), the slower will be the decrease in firmness and TA and the slower will be the change of skin colour. No alcohol flavour or physiological disorders developed in fruits stored at 0.7% O₂ and this concentration was recommended by Goffings *et al.* (1994). Hansen (1977) recommended 0–1 °C with 6% CO₂ and 2.5% O₂. Awad *et al.* (1993) recommended 1 °C for 6 months. Sharples and Stow (1986) recommended 1.5–2 °C with less than 1% CO₂ and 2% O₂ or less than 1% CO₂ 1.25% O₂. Johnson (1994) showed that a slight difference in temperature at the same controlled atmosphere conditions could have an affect on maximum storage life as shown below:

Temperature (°C)	CO ₂ (%)	O ₂ (%)	Storage time in weeks
1.5–2	<1	1.5–2	32
1.25	<1	1.5–2	36

Jonagold apples were stored at 1 °C and 85–90% r.h., either in a controlled atmosphere (7% CO₂, 7% O₂) or under normal atmospheric conditions. Weight losses and decay were negligible in controlled atmospheres (0.0–0.78%). Fruits stored in controlled atmosphere storage exhibited no physiological disorder (Jankovic and Drobnjak 1994). After storage at 3% O₂ with 1% CO₂ followed by 3 weeks of shelf life at 20 °C, scald was 23%. At 1.5% O₂ with 1% CO₂ and 3% O₂ with 5% CO₂, scald was 2% and 6%, respectively, while at 1.5% O₂ with 5% CO₂ no scald was observed. This shows that in Jonagold both O₂ and CO₂ affect the occurrence of scald. At high O₂ low CO₂ the level of scald (39%) was significantly higher in early harvested apples compared to apples from a normal harvest date (13% scald) (Awad *et al.* 1993). Jonagold apples were stored at 0 °C in air or in a controlled atmosphere. Controlled atmosphere storage at 0 °C 1.5% O₂ with 1.5% CO₂ for 6 months significantly reduced the loss of acidity and firmness, decreased production of volatile compounds by half, but did not influence total soluble solids content (Girard and Lau 1995). de Wild (2001) recommended 1 °C with 1.2%

O₂ and 4% CO₂. Anonymous 3 (n.d.) recommended 0–2 °C and 90–95% r.h. for 3 months in air and 1.3% O₂ + 4% CO₂ for the first month then 1–1.2% O₂ + 4% CO₂ or DCA for 9 months (ULO). It was reported to be not particularly susceptible to deficiencies during ripening, but storage in less than 1% O₂ can lead to a loss of flavour. When Jonagold apples were treated with 1-MCP, ethylene biosynthesis was almost completely suppressed throughout the whole postharvest life, with exception of the late harvested apples which regained some ethylene forming capacity after 2 weeks of shelf-life (Bulens *et al.* 2012). Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	0.8	1	2
Canada (British Columbia)	0	1.5	1.2
Canada (Nova Scotia)	0	4.5	2.5
Canada (Nova Scotia)	0	1.5	1.5
Denmark	1.5–2	<1	2
England	1.5–2	8	–
England	1.5–2	<1	2
France	0–1	2.5–3	1.5
Germany (Saxony)	2	1.7–1.9	1.3–1.5
Germany (Westphalia)	1–2	3–6	1–2
Holland	1	4	1–2
Slovenia	1	3	3
Slovenia	1	6	3
Slovenia	1	3	1.2
Spain	2	3–4	3
Switzerland	2	4	2
USA (New York)	0	2–3	1.8–2
USA (New York)	0	2–3	1.5

Jonathan

Naeve and Domoto (2008) recommended –1.1 to 0 °C and 90–95% r.h. 3–5 months. Anonymous (1968) recommended 0 °C with 3–5% CO₂ and 3% O₂ for 5–6 months. Stoll (1972) advocated 4 °C with 3–4% CO₂ and 3–4% O₂. Meheriuk (1993) suggested –0.5 to 4 °C with 1–3% CO₂ and 1–3% O₂ for 5–7 months. Fidler and Mann (1972), Fidler (1970) and Sharples and Stow (1986) recommended 4–4.5 °C with 6% CO₂ and 3% O₂. With Jonathan harvested at the optimum time, the loss of hardness after storage

until March or June was less in 0.9% O₂ and 4.5% CO₂ than 1.2% O₂ and 4.5% CO₂ directly after storage or after holding for 1 week at 20 °C but not after 2 weeks. With later-harvested fruits, O₂ concentration did not affect fruit hardness. However, flesh browning was greater in fruits stored in 0.9% O₂ than in 1.2% O₂ (Schaik 1994). Jonathan was shown to be sensitive to CO₂ injury, which appeared both externally and internally. The threshold for peel injury was 10% CO₂ and it occurred more severely and earlier at 15% O₂ than at 3% O₂ with little difference between the two O₂ levels at 20% CO₂. The development of superficial scald (which did not occur at 3% O₂) diminished at 15% O₂ with increasing CO₂ and was completely inhibited by 20% CO₂. Fruit softening was inhibited with increasing CO₂ levels in a similar manner at both O₂ levels, even though the higher O₂ level enhanced softening. No softening occurred at 20% CO₂ regardless of O₂ level both during storage and subsequent ripening. This could be related to the total inhibition of ethylene evolution which occurred at 20% CO₂ at both O₂ levels. Chlorophyll degradation was predominantly inhibited by increasing the level of CO₂ (Ben Arie *et al.* 1993). Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (south)	0	3	3
Australia (south)	0	1	3
Australia (Victoria)	2	1	1.5
China	2	2–3	7–10
Germany (Westphalia)	3–4	3	1–2
Israel	–0.5	5	1–1.5
Slovenia	3	3	3
Slovenia	3	3	1.5
Switzerland	3	3–4	2–3
USA (Michigan)	0	3	1.5

Jupiter

Sharples and Stow (1986) recommended 3–3.5 °C with less than 1% CO₂ and 2% O₂.

Karmijn

Hansen (1977) recommended a temperature of not lower than 4 °C with 3% CO₂ and 3% O₂.

Katy (Katja)

Sharples and Stow (1986) recommended 3–3.5 °C with less than 1% CO₂ and 2% O₂.

Kent

Sharples and Stow (1986) recommended 3.5–4 °C with 8–10% CO₂ and about 11–13% O₂ or less than 1% CO₂ and 2% O₂.

King Edward VII

Fidler and Mann (1972) recommended 3–4 °C with 8–10% CO₂ and about 11–13% O₂.

Lady Williams

Lady Williams were stored at 0 °C in a controlled atmosphere of 1.5% O₂ with less than 0.5% CO₂. Fruits were removed from storage after 3, 5, 7 and 9 months and assessed for storage life and sensory acceptability on return to air at 20° after 0, 4, 11, 18 and 25 days. Lady Williams is a late-maturing cultivar and the level of acidity (which decreased with time) is an important quality parameter for fruits of this cultivar (Jobling *et al.* 1993). Work in Australia showed that fruits can be stored for 6–8 months in 2% O₂ and 1% CO₂ at 0 °C (Tugwell and Chvyl 1995).

Laxton's Fortune

Sharples and Stow (1986) recommended 3–3.5 °C with 5% CO₂ and 3% O₂ or less than 1% CO₂ and 2% O₂ using a scrubber and 7–8% CO₂ for stores without a scrubber.

Laxton's Superb

Fidler (1970), Wilkinson and Sharples (1973) and Sharples and Stow (1986) recommended 3.5–4.5 °C with 7–8% CO₂ and 3% O₂ for 6 months.

Lodi

Naeve and Domoto (2008) recommended –1.1 to 0 °C and 90–95% r.h. for 1–2 weeks.

Lord Derby

Sharples and Stow (1986) recommended 3.5–4 °C with 8–10% CO₂ with data only available for stores without a scrubber.

Lord Lambourne

Sharples and Stow (1986) recommended 3.5–4 °C with 8% CO₂ with data only available for stores without a scrubber.

McIntosh

Naeve and Domoto (2008) recommended –1.1 to 0 °C and 90–95% r.h. for 3–4 months. Anonymous (1968) recommended 3.3 °C with 2–5% CO₂ with 3% O₂ for 6–8 months. Meheriuk (1993) recommended 2–4 °C with 1–5% CO₂ and 1.5–3% O₂ for 5–7 months. Sharples and Stow (1986) recommended 3.5–4 °C with 8–10% CO₂, with data only available for stores without a scrubber. Sharples and Stow (1986) recommended 3.5–4 °C with less than 1% CO₂ and 2% O₂. Hansen (1977) recommended for McIntosh-Rogers a temperature not lower than 3 °C with 6% CO₂ and 2.5% O₂. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Canada (British Columbia)	3	4.5	2.5
Canada (British Columbia)	3	5	2.5
Canada (British Columbia)	1.7	5	2.5
Canada (Nova Scotia)	3	4.5	2.5
Canada (Nova Scotia)	3	1.5	1.5
Canada (Ontario)	3	5	2.5–3
Canada (Ontario)	3	1	1.5
Canada (Quebec)	3	5	2.5
Germany (Westphalia)	3–4	3–5	2
USA (Mass.)	1–2	5	3
USA (Michigan)	3	3	1.5
USA (New York)	2	3–5	2–2.5
USA (New York)	2	3–5	4
USA (Penn.)	1.1–1.7	0–4	3–4

Melrose

Melrose apples were stored at 1 °C and 85–90% r.h., either in a controlled atmosphere (7% CO₂ with 7% O₂) or under normal atmospheric conditions. Weight losses and decay were negligible in controlled atmospheres (0–0.78%). Fruits stored in controlled

atmospheres exhibited no physiological disorders, whereas bitter pit was observed under normal atmospheric conditions (Jankovic and Drobnjak 1994). Hansen (1977) recommended 0–1 °C with 6% CO₂ and 2.5% O₂. Meheriuk (1993) recommended 0–3 °C with 2–5% CO₂ and 1.2–3% O₂ for 5–7 months. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Belgium	2	2	2–2.2
France	0–3	3–5	2–3
Germany (Westphalia)	2–3	3	1–2
Slovenia	1	3	3
Slovenia	1	3	1.2

Merton Worcester

Fidler (1970) recommended 3–3.5 °C with 7–8% CO₂ for stores with no scrubber or 5% CO₂ and 3% O₂ for stores with a scrubber.

Michaelmas Red

Fidler (1970) recommended 1–3.5 °C with 6–8% CO₂ for stores with no scrubber or 5% CO₂ and 3% O₂ for stores with a scrubber.

Monarch

Fidler (1970) recommended 0.5–1 °C with 7–8% CO₂ for stores with no scrubber or 5% CO₂ and 3% O₂ for stores with a scrubber.

Morgenduft

In Italy controlled atmosphere storage using ultra low O₂ regimes (0.9–1.1% O₂ compared to conventional levels of 2.5–3.0% O₂) controlled scald on Morgenduft fruits for 210 days. Fruits did not develop any alcoholic flavour or any external or internal visual symptoms of low O₂ injury, either during or after storage (Nardin and Sass 1994).

Mutsu

Fidler (1970) recommended 1 °C with 8% CO₂ with data supplied only for stores not fitted with a scrubber. Hansen (1977) recommended 0–1 °C with 6%

CO₂ and 2.5% O₂. Meheriuk (1993) recommended 0–2 °C with 1–3% CO₂ and 1–3% O₂ for 6–8 months. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (Victoria)	1	1	1.5
Australia (Victoria)	0	3	3
Denmark	0–2	3–5	3
Germany (Westphalia)	1–2	3–5	1–2
Japan	0	1	2
Slovenia	1	3	1
USA (Michigan)	0	3	1.5
USA (Pennsylvania)	–0.5 to +0.5	0–2.5	1.3–1.5

Newton Wonder

Controlled atmosphere storage was not recommended, only air storage at 1.1 °C for 6 months (Fidler 1970, Wilkinson and Sharples 1973).

Norfolk Royal

Fidler (1970) recommended 3.5 °C with 5% CO₂ and 3% O₂.

Northern Spy

Anonymous (1968) recommended 0 °C with 2–3% CO₂ and 3% O₂.

Pacific Rose

Johnston *et al.* (2001) recommended 0 °C.

Pink Lady (Cripps Pink)

Work in Australia showed that fruits could be stored at 0 °C in 2% O₂ and 1% CO₂ for up to 9 months without developing scald (Tugwell and Chvyl 1995). Burmeister *et al.* (2001) reported that an atmosphere of 2% O₂ + 2% CO₂ at 0.5 °C was likely to be appropriate. De Castro *et al.* (2007) used 0.5 °C with 1.5–2% O₂ + 1, 3, or 5% CO₂. Flesh browning was not observed in fruit stored in air at 0.5 °C but appeared in CA-stored fruit as soon as 2 months after harvest, but flesh browning incidence did not increase after longer storage periods. Flesh browning increased with increasing CO₂ concentration and

decreasing O_2 concentration in storage and delaying CA by 2 or 4 weeks reduced it. Pink Lady apples were reported not to be prone to rapid ripening, but storage life was compromised if harvest maturity was late and storage temperature was over 0°C for both storage in air or CA of 2% O_2 + less than 1% CO_2 (Jobling 2002a). She also reported that after 18 weeks of storage, internal browning varied depending on the orchard where they were harvested from 1–31% but there were similar levels in fruit stored in CA or air. Subsequently Jobling (2002b) reported preliminary results that suggested that flesh browning may be a function of limited O_2 and/or high CO_2 in storage and permeation of O_2 may be related to fruit density that is related to growing conditions and possibly greasiness of the skin relating to fruit maturity that may restrict gas exchange. The internal browning increased in incidence and severity during shelf life at 20°C following storage. The internal browning symptoms were mostly slight with approximately 5–25% of the surface of fruit cut at the equator affected with browning. Superficial scald did not occur in fruit stored in CA from any of the harvests or orchards. In air superficial scald began to be observed after 12 weeks of storage and increased in incidence and severity with greater storage duration. Superficial scald was less on fruit from later harvests. For storage in air Gualanduzzi *et al.* (2005) recommended 0°C for a maximum of 120 days for fruit harvested when they had light green-yellow ground colour, firmness of 7.5–8 kg force, starch degradation of 2.8–3.2 on a scale of 1–5, TSS of 15% and TA of 1–1.3 Meq 10 ml^{-1} . Villatoro *et al.* (2009) studied the effects of pre-storage treatment with Diphenylamine, folpet and imazalil contents of Pink Lady after storage at 1°C in air, 2% O_2 + 2% CO_2 or 1% O_2 + 1% CO_2 . After 27 weeks plus 7 days at 20°C diphenylamine and folpet levels in apple skin were lower for fruit that had been stored in air or 2% O_2 + 2% CO_2 than for those had been stored in 1% O_2 + 1% CO_2 . An additional storage period of 4 weeks in air reduced diphenylamine and folpet contents in whole apples stored for 13 weeks in the 2% O_2 + 2% CO_2 . For imazalil, the same result was obtained in apple skins stored for 27 weeks under in 1% O_2 + 1% CO_2 . Whale *et al.* (2008) reported that Cripp's Pink sprayed with AVG 5 weeks before harvest had retarded colour development at harvest, but Ethephon applied after AVG enhanced percentage red blush, anthocyanin

concentration and reduced chlorophyll concentration in the fruit. They also reported that Cripp's Pink grown in Western Australia often develops poor colour at commercial harvest resulting in economic losses. To determine if fruit colour could be improved without advancing ripening, Cripp's Pink apple fruit on the trees were sprayed with AVG alone, Ethephon alone, or AVG followed by Ethephon. The experiments were conducted at two different locations in Western Australia in 2002 and 2003. Fruit sprayed with AVG alone had retarded colour development at harvest. However, Ethephon applied after AVG enhanced percentage red blush, anthocyanin concentration and reduced chlorophyll concentration in the fruit skin in both locations. These fruit had similar colour to those treated with Ethephon alone. Internal ethylene concentration and fruit firmness were unaffected by the different treatments in 2002. However, in 2003 AVG with or without Ethephon reduced internal ethylene concentration and maintained firmness compared to Ethephon alone. In conclusion, AVG treatment alone delayed colour development and ripening of Cripp's Pink, while AVG application 5 weeks before harvest followed by an Ethephon application 2 weeks later enhanced red colour at commercial harvest (Whale *et al.* 2008).

Pinova

Maxin *et al.* (2012) reported significant reductions in the incidence of fruit rot by dipping them for 3 min at 50 – 54°C or rinsing them for 20 or 25 s at 55°C during storage of up to 100 days at 2°C followed by 14 days at 18°C .

Red Delicious

Naeve and Domoto (2008) recommended -1.1 to 0°C and 90–95% r.h. for 3–5 months. In South Tyrol, Italy controlled atmosphere storage, using ultra low O_2 regimes (0.9–1.1% O_2 compared to conventional levels of 2.5–3.0% O_2), controlled scald on Red Delicious fruits for about 150 days without the development of alcoholic flavour or any external or internal visual symptoms of low O_2 injury, either during or after storage (Nardin and Sass 1994). Red Delicious fruits stored for up to 7 months in 1–5% O_2 and 2–6% CO_2 had superficial scald levels of less than 3% (Xue *et al.* 1991). Van der Merwe (1996) recommended -0.5°C and 1.5% CO_2 with 1.5% O_2 for 9 months. Fidler (1970) and Sharples and Stow (1986)

recommended 0–1 °C with either 5% CO₂ and 3% O₂ or less than 1% CO₂ and 3% O₂. Meheriuk (1993) recommended –0.5 to 1 °C with 1–3% CO₂ and 1–2.5% O₂ for 8–10 months. Anonymous 3 (n.d.) recommended –1.5 to 1.1 °C and 90–95% r.h. for 3 months in air and 10 months in 1% O₂ + 1.5% CO₂ in ULO or DCA. It is susceptible to Scald and ULO storage gives effective control. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Australia (south)	0	1	2
Australia (Victoria)	0	1.5	1.5–2
Canada (British Columbia)	0–1	1	1.2–1.5
Canada (British Columbia)	0–1	1	0.7
Canada (Ontario)	0	2.5	2.5
Canada (Ontario)	0	1	1
France	0–1	1.8–2.2	1.5
Germany (Westphalia)	1–2	3	1–2
Israel	–0.5	2	1–1.5
Italy	0.5	1.5	1.5
New Zealand	0.5	2	2
South Africa	–0.5	1.5	1.5
Spain	0	2–4	3
USA (Mass.)	0	5	3
USA (New York)	0	2–3	1.8–2
USA (Penn.)	–0.5 to +0.5	0–0.3	1.3–2.3
USA (Washington)	0	<2	1–1.5

Ribstone Pippin

Fidler (1970) recommended 4–4.5 °C with 5% CO₂ and 3% O₂.

Rome Beauty

Anonymous (1968) recommended –1.1 to 0 °C with 2–3% CO₂ and 3% O₂.

Royal Gala

Work in Australia showed that fruits of Royal Gala can be stored for up to 5 months in 2% O₂ and 1% CO₂ at 0 °C (Tugwell and Chvyl 1995), but Stow (1996a) in the United Kingdom found that there was a large loss in flavour after 3 months of storage. Johnston *et al.* (2001) recommended 0 °C.

Spartan

Fidler (1970) recommended –1 to 0 °C with 5–8% CO₂ for stores with no scrubber or less than 1% CO₂ and 2% O₂ for stores with a scrubber. Sharples and Stow (1986) recommended 1.5–2 °C with 6%

CO₂ and 2% O₂ for 42 weeks. Meheriuk (1993) recommended 0–2 °C with 1–3% CO₂ and 1.5–3% O₂ for 6–8 months. Herregods (1993) and Meheriuk (1993) summarized general recommendations from a variety of countries as follows:

	Temperature (°C)	CO ₂ (%)	O ₂ (%)
Canada (British Columbia)	0	1.5	1.2–1.5
Canada (Ontario)	0	2.5	2.5
Canada (Quebec)	0	5	2.5–3
Denmark	0–2	2–3	2–3
England	1.5–2	<1	2
England	1.5–2	6	2
Switzerland	2	3	2–3
USA (New York)	0	2–3	1.8–2
USA (Penn.)	–0.5 to +0.5	0–1	2–3

Starking

Starking fruits were stored at –0.5 °C for 4 months in normal atmosphere, followed by 7 months in 1.5% O₂ and 2% CO₂. After storage the fruits were ripened at 20° for 7 days before evaluation for superficial scald. Starking fruits stored in controlled atmospheres were similar during 1988 and 1989 (Van Eeden *et al.* 1992). Starking Delicious could be stored for up to 9 months without appreciable loss of quality at 0 °C in 3% CO₂ with 3% O₂ (Ertan *et al.* 1992). Sfakiotakis *et al.* (1993) stored Starking Delicious fruit under various conditions including 2.5% O₂ with 2.5% CO₂ and ultra low O₂ (with 1% O₂ and 1% CO₂) storage all at 0.5 °C and 90% r.h. They showed that these conditions generally retarded fruit softening and markedly reduced scald development. 1% O₂ with 1% CO₂ was the most promising treatment for reducing fruit softening. Low O₂ without CO₂ was equally effective in extending fruit storage life, while 2.5% O₂ with 2.5% CO₂ storage gave moderate results. Sensory evaluation of fruits stored for 7–8 months in 2.5% O₂ with 2.5% CO₂ and 1% O₂ with 1% CO₂ gave high scores without any low O₂ injury or alcoholic taste. During storage, the ethylene scrubber used (Ethysorb) was effective in reducing the ethylene concentration in the gas phase below 0.3 µl L^{–1} in the 2.5% O₂ with 2.5% CO₂ and ultra low O₂ treatments and below 1.6 µl L^{–1} in air storage. However, internal fruit ethylene concentrations were found to be above the physiological levels capable of inducing ripening, even in the ultra low O₂ treatments. Calcium treatment delayed fruit

flesh softening in Starking Delicious apples (Guan *et al.* 1998).

Stayman

Anonymous (1968) recommended -1.1 to 0°C with 2–3% CO_2 and 3% O_2 .

Sundowner

Work in Australia showed that fruits can be stored in 2% O_2 and 1% CO_2 at 0°C with no adverse effects developing when fruit were stored below 1°C (Tugwell and Chvyl 1995).

Sunset

Sharples and Stow (1986) recommended 3 – 3.5°C with 8% CO_2 , with data only presented for stores without a scrubber.

Suntan

Sharples and Stow (1986) recommended 3 – 3.5°C with either 5% CO_2 and 3% O_2 or less than 1% CO_2 and 2% O_2 .

Tydemans' Late Orange

Sharples and Stow (1986) recommended 3.5 – 4°C with either 5% CO_2 and 3% O_2 or less than 1% CO_2 and 2% O_2 .

Undine

Hansen (1977) recommended a temperature of not under 2°C with 3% CO_2 and 2.5% O_2 .

Virginia Gold

Kamath *et al.* (1992) recommended 2.2°C with 2.5% O_2 and 2% CO_2 for up to 8 months. Under these condition fruits were firmer than those held in normal cold storage; they did not shrivel even when stored without polyethylene box liners and soft scald was eliminated.

Wealthy

Naeve and Domoto (2008) recommended -1.1 to 0°C and 90–95% r.h. for 3–10 weeks.

Winston

Sharples and Stow (1986) recommended 1.5 – 3.5°C with 6–8% CO_2 , with data only presented for stores without a scrubber.

Worcester Pearmain

Fidler (1970) recommended 0.5 – 1°C with 7–8% CO_2 for stores with no scrubber or 5% CO_2 and 3% O_2 for stores with a scrubber. Wilkinson and Sharples (1973) suggested 0.6 – 1.1°C with 5% CO_2 and 3% O_2 for 6 months. Sharples and Stow (1986) advocated 0.5 – 1°C and 7–8% CO_2 for fruit stored without a scrubber and 5% CO_2 with 3% O_2 for those stored with a scrubber.

Diseases

In Lithuania Kviklienė *et al.* (2011) reported that for the cultivar Lodel rotting of fruit caused by *Monilinia* sp., *Gloeosporium* spp. and *Penicillium* spp. and bitter rot caused by *Gloeosporium album* were the most common storage diseases. It has been common practice for many years to drench apples with a fungicide just before they are loaded into store. However, legislation on the postharvest use of fungicides is being increasingly restrictive. Spraying the crop during growth can reduce postharvest infections. In Britain single sprays with 0.025% benomyl in June, July or August to apple trees controlled rots, caused by infection with *Gloeosporium* spp, which developed in subsequent storage from September onwards at 3.3°C in fruit from unsprayed trees. The observations were made over two seasons and the fungicide applied at 1120 L ha^{-1} (Edney *et al.* 1977). With the pressure against the use of postharvest fungicides, various biological control methods have proved to be successful (Teixido *et al.* 1999). Maxin *et al.* (2012) found significant reductions of fruit rot by postharvest dipping in water for 3 min at 50 – 54°C . After 100 days of storage at 2°C and 14 days at 18°C the pathogens controlled were *Neofabraea alba*, *N. perennans*, *Monilinia fructigena*, *Colletotrichum acutatum*, *Phacidiopycnis washingtonensis* and *Cladosporium* spp. *Neonectria galligena* was reliably controlled. No effects of either heat treatment on *Gibberella avenacea* and *Botrytis cinerea* were apparent. The incidence of *P. washingtonensis*, *Penicillium expansum*, *Mucor* spp. and *Phoma exigua* was higher following rinsing at 65°C for 20 s than in untreated fruit or in those rinsed at lower temperatures and was associated with heat damage. Lima *et al.* (2012) found that the integration of biocontrol yeasts (*Rhodospiridium kratochvilovae* LS11 and *Cryptococcus laurentii* LS28) with a low rate of the recently commercialized fungicides boscalid and cyprodinil

could be an effective and safer strategy to control *P. expansum* and kept fungicide residues as well as patulin contamination in low. Mari *et al.* (2012) found that treating Gala fruit with two *Aureobasidium pullulans* antagonists, isolated from peaches, applied at 108 CFU ml^{-1} controlled over 86% of decay caused by artificially inoculated *B. cinerea*, *C. acutatum* and *P. expansum*.

Physiological disorders

A more comprehensive discussion of the subject can be found in Fidler *et al.* (1973) and Snowdon (1990). The principal disorders are given in the following sections.

Superficial scald

Scald is a physiological disorder that can develop on apples and pears during storage and has been associated with ethylene levels in the store, which results in the skin turning brown. Scald susceptibility in Delicious apples was found to be strain dependent. While storage in 0.7% O_2 effectively reduced scald in Starking and Harrold Red fruits picked over a wide range of maturity stages, but it did not adequately reduce scald in Starkrimson fruits after 8 months of storage (Lau and Yastremski 1993). To control scald Van der Merwe (1996) suggested storage at -0.5°C and 0–1% CO_2 with 1.5% O_2 for 7 months. Granny Smith apples were stored at -0.5°C for 6 months in normal atmosphere, for 9 months in 1.5% O_2 and 0% CO_2 and after storage they were ripened at 20° for 7 days before evaluation. In a normal atmosphere, all control fruits developed superficial scald, but only a few in controlled atmosphere storage developed scald (Van Eeden *et al.* 1992). Scald can also be controlled by a prestorage treatment with an antioxidant. Ethoxyquin (1,2-dihydro-2,2,4-trimethylquinoline-6-yl ether) marketed as Stop-Scald or DPA (diphenylamine) marketed as No Scald or Coraza should be applied directly to the fruit within a week of harvesting. In the United States the government approved the postharvest application of these two chemicals to apples with maximum residues of $3 \mu\text{L L}^{-1}$ for Ethoxyquin and $10 \mu\text{L L}^{-1}$ for DPA (Hardenburg and Anderson 1962). Residue levels of DPA in apples were found to vary depending on the application method and

the position of the fruit in the pallet box. There are restrictions on the sale of treated fruits in several countries and local legislation should be consulted before they are applied. Different cultivars of apples respond differently to these treatments, for example only DPA is effective in controlling scald on the Delicious cultivars. Successful application of DPA, ethoxyquin and captan to Granny Smith, Delicious and Golden Delicious apples in cold stores, by thermal fogging and thermonebulization, was described by Sive and Resnizky (1979).

Ilinski *et al.* (2000) found that exposure of apples to 19–21% CO_2 for 2–4 days followed by controlled atmosphere storage resulted in good scald control, whereas a short exposure of 1–5 h had no such effect. After controlled atmosphere storage for 250 days, fruit firmness, acidity and overall sensory acceptability of fruits were similar in treatments with initial O_2 reduction by respiration compared to traditional atmosphere establishment. Fidler *et al.* (1973) also showed that scald development in storage could be related to the CO_2 and O_2 levels but that the relationship varied between cultivars (Table 55).

Core flush

This disorder is also called brown core and has been described on several cultivars where it develops during storage as a brown or pink discoloration of the core while the flesh remains firm. It has been associated with CO_2 injury but may also be related to chilling injury and senescent breakdown. The effects of O_2 shock treatment on physiological disorders have also been described. Johnson and Ertan (1983) found that at 4°C in 1% O_2 the fruits were free

Table 55 Effects of controlled atmosphere storage conditions during storage at 3.5°C for 5–7 months on the development of superficial scald in three apple cultivars (source: adapted from Fidler *et al.* 1973)

Storage conditions		Cultivar		
CO_2	O_2	Wagener	Bramley's Seedling	Edward VII
0	21	100	–	–
0	6	–	89	75
0	5	100	–	–
0	4	–	85	62
0	3	9	30	43
0	$2\frac{1}{2}$	–	17	43
0	2	0	–	–
8	13	–	24	3

of core flush and other physiological disorders and their quality was markedly better than those stored in 2% O₂. Keeping apples in 0% O₂ for the first 10 days of storage and was shown to prevent core flush in early-picked Jonathan from highly affected orchards. Wang (1990) reviewed the effects of CO₂ and concluded that core flush was due to exposure to high levels of CO₂ at low storage temperatures. No damage due to anaerobic respiration was observed in any of the treatments (Resnizky and Sive 1991).

Bitter pit

Bitter pit (Figure 1) is principally associated with calcium deficiency during the period of fruit growth and may be detectable at harvest or sometimes only after protracted periods of storage. In addition to low fruit calcium, Ferguson and Watkins (1989) reported that preharvest factors associated with high bitter pit incidence included high Mg and K at harvest, large fruit volume, and weight and high position of fruit on the tree. De Freitas *et al.* (2010) reported that it was a complex process that involves the total input of calcium into the fruit, but also a proper calcium homeostasis at the cellular level. They found that calcium accumulation into storage organelles and calcium binding to the cell wall represented an important contributor to bitter pit development. The addition of lecithin (phosphatidyl choline) to the postharvest application of calcium can enhance its effect in controlling bitter pit (Sharples *et al.* 1979). At 18 °C apples treated with 4% calcium chloride had a slightly lower respiration rate, but this effect was greatly enhanced when lecithin (1%) was added. At 3 °C lecithin-treated apples had reduced ethylene production but no effect on CO₂ production (Watkins *et al.* 1982).

Braeburn browning disorder

Braeburn fruit can develop Braeburn browning disorder (BBD) during hypoxic cold storage in elevated levels of CO₂. Pre-storage treatment with the antioxidant diphenylamine (DPA) can prevent this disorder. Lee *et al.* (2012b) treated Braeburn fruit with 2 g L⁻¹ and stored them at 0.5 °C with 1.5% O₂ + 3% CO₂ for up to 12 weeks. They found that flesh browning was associated with increased acetaldehyde, ethanol and ethyl esters. DPA treatment reduced the levels of

these and other volatile compounds and many amino acids. 1-MCP-treated Braeburn fruit in both 1.5% O₂ + 1.0% CO₂ and dynamic controlled atmosphere storage (DCA) showed a higher incidence of Braeburn browning disorder (on average + 53%) than non-treated fruit. DCA storage reduced Braeburn browning disorder to 46% compared to fruit stored only in 1.5% O₂ + 1.0% CO₂ (Lafer 2008).

Apricot

Rosaceae

Prunus armeniaca L. also called damasco, albaricoque and Siberian apricot. It is a tree that grows up to about 8 or 9 m high with white or rarely pink flowers. The fruit is a drupe and the skin varies in colour with different cultivars from pale yellow to deep orange with red freckles. The chemical content was given by USDA (2012) in Table 56. Total world production in 2010 was estimated by FAO (2013) as 3,461,697 tonnes.

Harvesting

If harvested immature they lack the full flavour of tree-ripened fruit (Fidler 1963, Lutz and Hardenburg 1968). Skin colour is commonly used to judge harvest maturity. Fan *et al.* (2000) defined maturity stage 1 as light green, partially turning to a straw colour and maturity stage 2 as straw colour on most of the fruit surface. In South Africa the Deciduous Fruit Board produced a colour chart: AP.1. Jooste and Taylor (1999) recommended that the cultivar Bebeco be harvested between values of 4 and 6 on that chart as the primary indicator of harvest maturity. They also found that flesh firmness as measured by a penetrometer of between 8.0 and 11.5 kg could be used as a very reliable secondary indicator. Total soluble solids content of the juice is also used (Botondi *et al.* 2000). Softening was used to determine fruit harvest maturity by Claypool (1959) and Rood (1957). As the fruit matures and ripens the chlorophyll content reduces so that light transmission properties of fruit can be used to measure objectively chlorophyll content and therefore their ripeness. The wavelength used for apricots was 380–730 nm, and

Table 56 The composition of apricot fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.35 g	Thiamine	0.030 mg
Energy	48 kcal	Riboflavin	0.040 mg
Protein	1.40 g	Niacin	0.600 mg
Total lipid (fat)	0.39 g	Vitamin B-6	0.054 mg
Carbohydrate, by difference	11.12 g	Folate	9 µg DFE
Total dietary fibre	2.0 g	Vitamin B-12	0.00 µg
Total sugars	9.24 g	Vitamin A	96 µg RAE
Calcium	13 mg	Vitamin A	1926 IU
Iron	0.39 mg	Vitamin E (α-tocopherol)	0.89 mg
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	23 mg	Vitamin D	0 IU
Potassium	259 mg	Vitamin K (phylloquinone)	3.3 µg
Sodium	1 mg	Fatty acids, total saturated	0.027 g
Zinc	0.20 mg	Fatty acids, total monounsaturated	0.170 g
Total ascorbic acid	10.0 mg	Fatty acids, total polyunsaturated	0.077 g

the correlation coefficient with organoleptic measurements was in the range 0.84–0.93 (Yeatman and Norris 1965, Czabaffy 1984; 1985).

Prestorage treatments

Fruits of the cultivar Perfection were treated with 1 µl L⁻¹ of 1-MCP for 4 h at 20 °C then stored at 0 or 20 °C. The onset of ethylene production was delayed, respiration rate was reduced and the reduction in firmness and TA was slower following the 1-MCP treatment compared to those not treated with 1-MCP. These effects were similar both temperatures. 1-MCP also delayed the production of volatile alcohols and esters during ripening at 20 °C, and they had less colour change than those not treated (Fan *et al.* 2000). 1-MCP at 10 µl L⁻¹ reduced ethylene production, respiration rate and softening of the cultivar Patterson during ripening at 20 °C (Muñoz-Robredo *et al.* 2012). They also reported that AVG at 1 g L⁻¹ had similar effects to 1-MCP.

Postharvest physiology

The fruit was classified as climacteric. Crisosto and Kader (2002a) reported that their ethylene production rate during storage was related to temperature. At 0 °C it was less than 0.1 µl kg⁻¹ h⁻¹, while at 20 °C it was 4–6 µl kg⁻¹ h⁻¹ for firm-ripe fruit and higher for soft-ripe fruit. Exposure to ethylene-hastened ripening as indicated by softening and colour changes from

green to yellow but exposure to ethylene may encourage growth of decay causing fungi. They also gave the following for respiration rates as: 4–8 at 0 °C, 12–20 at 10 °C, 30–50 mg CO₂ kg⁻¹ h⁻¹ at 20 °C.

Storage

Their shelf life in a simulated room temperature of 20 °C and 60% r.h. was shown to be only 1–2 days (Mercantilia 1989). Refrigerated storage recommendations include:

- –0.5 to 0 °C and 85–95% r.h. for 1–2 weeks (Phillips and Armstrong 1967, Hardenburg *et al.* 1990).
- 0 °C and 90% r.h. for 1–2 weeks (Mercantilia 1989).
- –1 to 0 °C 90–95% r.h. for 1–4 weeks (Snowdon 1990).
- –0.5 °C and 90–95% r.h. for 7–14 days (SeaLand 1991).
- 0 °C (Fan *et al.* 2000).
- –0.5 to 0 °C with 90–95% r.h. for 1–4 weeks depending on the cultivar (Crisosto and Kader 2002a).

Controlled atmosphere storage

J. E. Bernard in 1819 in France (quoted by Thompson 2010) showed that apricots could be successfully stored in atmospheres containing no O₂ for up to 28 days then removed to air for ripening. Controlled

atmosphere storage can lead to an increase in internal browning in some cultivars (Hardenburg *et al.* 1990). A 1% O₂ atmosphere maintained acceptable firmness and colour during storage at 15 °C for fruit harvested with 13–14 °Brix. Early harvested fruits, with 9–10 °Brix, did not benefit from low O₂ (1 or 2%) storage because they had not reached the optimal total soluble solids content, whereas for late harvest fruit (13–14 °Brix) the use of 1% O₂ at a higher temperature (15 °C) than that used commercially can be an alternative to low temperature (5 °C) for shipping or short-term storage (Botondi *et al.* 2000). Other recommendations include:

- 0–5 °C with 2–3% CO₂ and 2–3% O₂ but not to be used commercially (Kader 1985, 1989).
- 0 °C with 2.5–3% CO₂ with 2–3% O₂ for Blenheim (Royal) retained their flavour better than air-stored fruit when they were subsequently canned (Hardenburg *et al.* 1990).
- 2–3% CO₂ with 2–3% O₂ (SeaLand 1991).

Exposure to less than 1% O₂ may result in the development of off-flavours and greater than 5% CO₂ for longer than 2 weeks can cause flesh browning and loss of flavour. Pre-storage treatment with 20% CO₂ for 2 days may reduce incidence of decay during subsequent transport in air or CA storage (Crisosto and Kader 2002a).

Hypobaric storage

Haard and Salunkhe (1975) found that storage life could be extended from 53 days in cold storage to 90 days in cold storage combined with reduced pressure of 102 mm Hg. They found that hypobaric storage delayed carotinoid production, but after storage carotinoid, sugar and acid levels were the same as those in cold storage alone.

Ripening

Optimum ripening can be achieved at 18–24 °C (Hardenburg *et al.* 1990). Fruits that were harvested while they were still green and kept for 3 days at 19 °C with 1000 µl L⁻¹ ethylene for the first 24–48 h lacked the aroma and flavour of fruits which were left on the trees for a further 6 or 7 days to ripen naturally (Fideghelli *et al.* 1967).

Diseases

Brown rot is caused by *Monilia fructicola* and is probably the most important postharvest disease of apricot. Infection begins during flowering and fruit rots may occur before harvest, but often occur postharvest. Orchard sanitation to minimize infection sources, pre-harvest fungicide application and prompt cooling after harvest are control strategies. In trials on injured fruit with extracts obtained from the wild edible herbaceous species, *Sanguisorba minor*, extract completely inhibited brown rot and *Orobanche crenata* extract strongly reduced brown rot (Gatto *et al.* 2012). Rhizopus rot is caused by *Rhizopus stolonifer* and it was reported to occur frequently in ripe or near-ripe fruit stored at 20–25 °C. Cooling fruit and storage below 5 °C is an effective control method (Crisosto and Kader 2002a).

Arbutus

Ericaceae

Arbutus unedo L. synonymous with *Unedo edulis* Hoffmanns and *A. vulgaris* Bubani. Common names include strawberry tree and cane apple. It is widespread in the Mediterranean region including Portugal, Spain and south eastern France, Algeria, Morocco, Tunisia, Italy, Greece, Turkey, Cyprus, Lebanon and Syria. It is also found in western France, Albania, Bulgaria, Croatia and south western Ireland. Its fruits are eaten fresh and also commonly used in Portugal in the production of brandy and in France for liqueurs, jams and confectionery in folk medicine (Oliveira *et al.* 2011a). It is an evergreen shrub or small tree up to 9 or 10 m high. It has creamy white or pinkish hermaphrodite bell-shaped flowers borne in long drooping panicles of 10–30 flowers. The fruit is a red warty berry up to 2 cm in diameter (Harrison *et al.* 1985). Oliveira *et al.* (2011b) identified the main volatile compounds as (*Z*)-3-hexen-1-ol, 1-hexanol, hexanal, (*E*)-2-hexenal and hexyl acetate, all formed through the lipoxygenase pathway. The green odours were progressively replaced during ripening by floral and sweet odours, owing to the decrease in alcohols, aldehydes and esters, resulting in the unmasking of the aromas associated with the minor compounds (mainly monoterpenes and norisoprenoid compounds). Oliveira *et al.* (2011a) established correlation between antioxidant activity

and fruits ripening stage. Fatty acid profiles were very similar between the ripening stages, being α -linolenic, linoleic and oleic, the three major ones. Polyunsaturated fatty acids represented as much as 60% of the total fatty acids, with a highly favourable omega 3 : omega 6 ratio. The most important vitamin E vitamer was γ -tocotrienol with a clear reduction in the total free vitamin E content during ripening. Total phenol contents were higher in the unripe and intermediate stages of ripeness than in fully ripe fruit.

Gago *et al.* (2012) dipped fruit for 2 min in solutions of distilled water (control), 0.01% Citral, 0.6% Natureseal and 0.6% Natureseal + 0.01% Citral, all weight for volume and then stored for up to 22 days. Panelists rated treatment with Natureseal + Citral preserved fruit quality better than the other treatments. They also commented that only small quantities are used for fresh consumption despite its excellent flavour, owing to high perishability.

Asian pears

Rosaceae

Pyrus spp. Other common names include Chinese pear, Japanese pear and nashi. The cultivated varieties of Chinese and Japanese pears were developed from *P. ussuriensis* Maximowicz, *P. serotina* Rehder (synonymous with *P. pyrifolia* [Burman] Nakai) and possibly other native species (Kikuchi 1948, quoted by Crisosto 2002). They are closely related to the European pear *P. communis*. There is also the Chinese

sand pear (*P. sinensis*), which produces a rather insipid fruit. They are large deciduous trees whose fruit is a pome, which tend to be spherical rather than pear shaped. They have a golden russet brown skin and crisp white, juicy, granular flesh. Sirisomboon *et al.* (2000) indicated that the fruit were firm, sweet and juicy, bruise more easily than European pears and ripen on the tree rather than postharvest. The freezing point was given as -1.5°C but it will vary depending on TSS (Crisosto 2002). The chemical content was given by USDA (2012) in Table 57.

Harvesting

In Japan commercial harvesting starts around late August to early September some 70 days after pollination. Fruit grown in California and picked later than 180 days after full bloom were likely to develop browning during storage. Fruit harvested when the skin was completely yellow may develop internal browning within 1 month after harvest (Crisosto 2002).

Prestorage treatments

1-MCP treatment was effective in maintaining quality during long-term cold storage of the cultivars Gold Nijisseiki and Hosui (Itai and Tanahashi 2008). The cultivar KS6 of *P. serotina* were treated with $2\ \mu\text{L L}^{-1}$ 1-MCP and stored at 1°C and 90–95% r.h. for up to 120 days. 1-MCP-treated fruit were firmer and skin colour change was delayed compared to those that had not been treated. Scald appeared early

Table 57 The composition of Asian pear fruit for $100\ \text{g}^{-1}$ fresh weight (source: adapted from USDA 2012)

Water	88.25 g	Thiamine	0.009 mg
Energy	42 kcal	Riboflavin	0.010 mg
Protein	0.50 g	Niacin	0.219 mg
Total lipid (fat)	0.23 g	Vitamin B-6	0.022 mg
Carbohydrate, by difference	10.65 g	Folate	8 μg DFE
Total dietary fibre	3.6 g	Vitamin B-12	0.00 μg
Total sugars	7.05 g	Vitamin A	0 μg RAE
Calcium	4 mg	Vitamin A	0 IU
Iron	0.00 mg	Vitamin E (α -tocopherol)	0.12 mg
Magnesium	8 mg	Vitamin D (D2 + D3)	0.0 μg
Phosphorus	11 mg	Vitamin D	0 IU
Potassium	121 mg	Vitamin K (phylloquinone)	4.5 μg
Sodium	0 mg	Fatty acids, total saturated	0.012 g
Zinc	0.02 mg	Fatty acids, total monounsaturated	0.049 g
Total ascorbic acid	3.8 mg	Fatty acids, total polyunsaturated	0.055 g

during storage and was reduced, but not entirely eliminated, with 1-MCP (Yazdani *et al.* 2011). The cultivars Laiyang Chili and Ya Li were treated with 3, 6 or 9% emulsions of commercial or refined (reduced α -tocopherol levels) plant oils at harvest and then stored at 0 °C for 6 months by Ju *et al.* (2000). The oils were from soya bean, maize, groundnut, linseed and cotton seed and they all had similar effects. Ethylene production and respiration rate in fruits treated with 9% oils were lower during the early part of storage and higher in the later part than that in the controls. After 6 months of storage at 0 °C and 7 days at 20 °C, it was found that the oils applied at 9% inhibited internal browning completely, at 6% they reduced it and at 3% was not effective. Pears treated with oils maintained fruit colour, firmness, TSS and TA in proportion to oil concentration during storage. Internal ethanol was not affected by oil treatment compared to those not treated, either during storage or after 7 days subsequently at 20 °C and no off-flavours were detected by sensory evaluation in any of the fruits.

Postharvest physiology

The respiration rate of Asian pears was 2–8 mg CO₂ kg⁻¹ h⁻¹ at 0 °C and 20–30 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Crisosto 2002). Their shelf life was found to be determined by their level of ethylene production. Exposure to relatively high levels of ethylene reduced storage potential and fruit quality (Itai *et al.* 1999). However, Inaba *et al.* (1989) found that there was no change in respiration rate from exposure to ethylene at 100 µl L⁻¹ for 24 h at any temperature between 5 and 35 °C. The cultivars Nijisseiki, Kosui and Niitaka produced less than 0.1 µl kg⁻¹ h⁻¹ ethylene and had a non-climacteric respiratory pattern. The cultivars Tsu Li, Ya Li, Chojuro, Shinsui, Kikusui and Hosui had a climacteric respiratory pattern and Tsu Li and Ya Li produced ethylene up to 9–14 µl kg⁻¹ h⁻¹, while in other cultivars it produced ethylene in the range of 1–3 µl kg⁻¹ h⁻¹ at 0 °C. Exposure of cultivars showing a climacteric respiratory pattern to greater than 1 µl L⁻¹ ethylene had accelerated the loss of green colour and slightly increased softening at 20 °C but the effects at 0 °C were minimal (Crisosto 2002).

Storage

Forced-air cooling was not recommended because work done in New Zealand indicated that there was

no benefit from rapid pre-cooling and it may result in a higher incidence of flesh spot decay during storage if they have been rapidly cooled within 24 h of harvest (Crisosto 2002). Refrigerated storage recommendations were:

- 2 °C for 6 months for Early Gold (Zagory *et al.* 1989).
- 1.1 °C and 90–95% r.h. for 150–180 days (SeaLand 1991).
- 0.5 °C (Park and Kwon 1999).
- 0 °C for 6 months for Chinese pear (Ju *et al.* 2000).
- 0 °C ± 1 °C and 90–95% r.h. (Crisosto 2002).

Controlled atmosphere storage

Low O₂ atmospheres reduced yellow colour development, compared to air. The cultivar 20th century was shown to be sensitive to CO₂ concentrations above 1% when exposed for longer than 4 months or to 5% CO₂ when exposed for more than 1 month (Kader, quoted by Zagory *et al.* 1989). The cultivar Shinko became prone to internal browning, perhaps owing to CO₂ injury, after the third month in storage (Zagory *et al.* 1989). A storage experiment at 2 °C in 1, 2 or 3% O₂ of the cultivars Early Gold and Shinko showed no clear benefit compared to storage in air (Zagory *et al.* 1989). Kader (1989) recommended 0–5 °C with 0–1% CO₂ and 2–4% O₂ which, however, had limited commercial use. Meheriuk (1993) indicated that controlled atmosphere storage of Nashi was still in an experimental stage but gave provisional recommendations of 2 °C with 1–5% CO₂ and 3% O₂ for about 3–5 months and that longer storage periods may result in internal browning. Crisosto (2002) found that storage duration of some cultivars could be extended by 25% in CA conditions compared to storage in air, but they were sensitive to injury at greater than 2% CO₂ for most cultivars when stored for more than 1 month. He recommended 1–3% O₂ for some cultivars (such as Nijisseiki) or 3–5% for others (such as Ya Li) to help retain firmness and delay changes in skin colour. Meheriuk (1993) also stated that some cultivars are subject to CO₂ injury but indicated that this is only when they are stored in concentrations of over 4%. Crisosto (2002) reported that exposing Nijisseiki to ≤ 1% O₂ for 4 months at 0 °C and from exposing Ya Li and Tsu Li to ≤ 1% O₂ for 2 months ≤ 2% O₂ for 4 months or ≤ 3% O₂

for 6 months at 0 °C caused injury. CO₂ toxicity was described as core or medial flesh browning, with cavities developing in severe cases as a result of desiccation of dead tissue. These symptoms occurred on Ya Li exposed to $\geq 5\%$ CO₂ for 6 weeks at 0 °C.

Physiological disorders

Pears suffer from a whole range of physiological disorders including bitter pit. The physiological disorders in European pears and apples and were reviewed by Snowden (1990). The development of brown to dark-brown water-soaked areas in the core and/or flesh occurs during storage, with no visible external indication of internal browning. Internal browning or core breakdown is the main worldwide consumer complaint and can be a problem in some cultivars including Ya Li, Daisui Li, Seuri, Tse Li, Shin Li, Shingo, Okysankichi and Dan Be. Fruit grown in California and harvested later than 180 days after full bloom (3000 degree days) were likely to develop browning during storage. The fruit should be picked when most of the pears on the tree are still green, although it is alright if a few at the top have begun to develop some light-yellow spots. Fruit picked when the skin is completely yellow will develop internal browning within 1 month after harvest. In China, reduction of internal breakdown of Ya Li was achieved by decreasing the storage temperature gradually from ambient to 0 °C (Ju *et al.* 2000, Crisosto 2002).

Symptoms of flesh spot decay include partial browning of spots and/or development of cavities in the flesh along and around the vascular bundles when the symptoms are severe, but there is no external indication of the disorder. Cavities are usually dry and surrounded by apparently healthy tissue. It can occur in fruit while still on the tree, but it is usually more obvious after 2–6 weeks of cold storage. It is more frequent on large and over-mature fruit but its cause is still unknown and it may be related to climatic factors (Crisosto 2002).

Watercore symptoms include glassy diffuse water-soaked areas in flesh; affected areas may taste sweet and turn slightly brown. Watercore occurs under conditions favouring vigorous tree growth on some cultivars e.g. Nijisseiki, Shinseiki and Hosui (Crisosto 2002).

Superficial scald or skin browning produces scald-like browning symptoms on the skin and can occur during long-term storage. It has been observed on the cultivars Shinsiki and Nijisseiki. Initially, the affected areas of the skin are light brown in colour, but as the disorder progresses the skin becomes dark brown and develops a bronze, scald-like appearance similar to superficial scald in apples (Crisosto 2002). Fruits of the cultivar Niitaka were harvested at their commercial harvest time and cured at ambient temperatures of about 18 °C for 5, 10 or 15 days followed by step-wise cooling until equilibrium at 0.5 °C. Skin blackening is a physiological problem during storage of Niitaka but it was observed only in fruits stored without curing. Curing treatments did not significantly alter other fruit quality characteristics during storage but affected the physical properties of the fruit's epidermis (Park and Kwon 1999).

Assyrian plum

Boraginaceae

Cordia myxa L. Common names include burgund, geduri, gonda, lasora, lasura, lehusa, naruvilli, panugeri, pidar and spistan. It is found growing throughout tropical Asia from Myanmar in the east to Afghanistan in the west especially in the Indian subcontinent. It grows from about 200 m above mean sea level to about 1500 m in arid and semi-arid regions in tropical to subtropical climates and can survive in saline and alkaline conditions, but sandy loam was considered optimum. Ripe fruits are eaten raw and unripe fruits are pickled or used as vegetables. The ripe fruits contain an anionic polysaccharide having good adhering properties. Haq *et al.* (2013) extracted Gum Cordia from the fruit and compared it with carboxy methyl cellulose as a fruit coating for the preservation of pine nuts called chilgoza (*Pinus gerardiana*) in Pakistan. Chilgoza coated with Gum Cordia had about 95% longer shelf life compared to those not treated and was also superior to CMC.

It is a medium-sized broad-leaved evergreen or partially deciduous tree that grows up to 15 m high. Flowers are small, white and usually pentamerous. The fruit is drupe up to 3 cm long with yellowish brown, pink or white skin. Aberoumand (2011a) gave the following composition of fruits

in Iran: protein $8.32 \pm 0.27\%$, lipid $2.2 \pm 0.50\%$, carbohydrates $57.08 \pm 0.68\%$, fibre $25.7 \pm 0.35\%$, ash $6.7 \pm 0.80\%$ and calorific value 281.4 ± 5.31 kcal 100 g^{-1} . He also reported the presence of alkaloids, saponin, steroids and polyphenols as well as 1500 mg 100 g^{-1} of calcium, 29 mg 100 g^{-1} of iron, 1800 mg 100 g^{-1} of potassium and 55 mg 100 g^{-1} of sodium. Aberoumand (2011b) reported that fruit contained 4.02 mg g^{-1} of total phenolics, 248 mg 100 g^{-1} of phytic acid and 1.39 TIU g^{-1} of trypsin inhibitors.

Atemoya

Annonaceae

Atemoya is a bi-specific hybrid between the sugar apple (*Annona squamosa* L.) and the cherimoya (*A. cherimolia* Mill.). It is a small tree grows up to about 6 or 7 m high and produces fruit that are fleshy syncarps formed by the fusion of the pistils and receptacle with custard-like sweet pulp containing many hard seeds.

Postharvest physiology

They are climacteric fruit and ethylene production rate was $100\text{--}300\text{ }\mu\text{L kg}^{-1}\text{ h}^{-1}$ at 20°C and ripening was accelerated by exposure to $100\text{ }\mu\text{L L}^{-1}$ for 24 h (Paull and Chen 2002a). They also gave their respiration rate as 48–190 at 10°C , 54–281 at 15°C , 40–460 mg $\text{CO}_2\text{ kg}^{-1}\text{ h}^{-1}$ 20°C . Paull (1996) found that fruits tended to split during maturation. He found that in the cultivars African Pride and Gefner splitting coincided with a threefold increase in total soluble solids, which resulted in osmotic and turgor changes during ripening leading to the movement of water from the skin, and possibly the receptacle, to the flesh. The increase in receptacle diameter increased the stress on the flesh and skin, leading to fruit splitting. In the cultivar African Pride stored at 20°C the major changes during ripening were a continuous decrease in starch, a continuous increase in fructose and glucose, an increase in sucrose to a maximum at the peak climacteric, an increase in malic acid early in the climacteric rise and a decrease in ascorbic acid after the peak climacteric. Eating quality was optimal 2 days after the climacteric peak (Wills *et al.* 1984a).

Storage

Storage at 0, 5 or 10°C all resulted in chilling injury (Wills *et al.* 1984a). Batten (1990) found that fruits stored at 4°C and high humidity for more than 2 days developed symptoms of chilling injury, which were blackening of skin and browning of flesh, although even after 5 days at 4°C fruits that were then ripened at 20°C had a very good flavour. Chilling injury can also result in loss of aroma and flavour (Paull and Chen 2002a). Storage recommendations include:

- 25°C for 4 days (Wills *et al.* 1984a).
- 20°C for 5 days (Wills *et al.* 1984a).
- 15°C for 8 days (Wills *et al.* 1984a).
- 8°C for 1 week for the cultivars Africa Pride, Pink's Mammoth, Neilsen and QAS (Brown and Scott 1985).
- 12°C or $15\text{--}16^\circ\text{C}$ for 2 weeks for the cultivars Africa Pride, Pink's Mammoth, Neilsen and QAS (Brown and Scott 1985).
- 12°C for 6 days followed by ripening for 3 days at 20°C (Batten 1990).
- 12.8°C and 85–90% r.h. for 28–42 days (SeaLand 1991).
- $10\text{--}13^\circ\text{C}$ with 90–95% r.h. (Paull and Chen 2002a).

Ripening

At 20°C the ripening time was about 5 days for freshly harvested fruit (Batten 1990). Wills *et al.* (1984a) also recommended 20°C for 5 days for optimum eating quality. Fruits ripened more quickly and with good flavour at 28°C , while ripening was slower and the quality impaired at 32°C (Batten 1990).

Arazá

Myrtaceae

Eugenia stipitata MacVaugh. McVaugh (1956) also divided the species into *E. stipitata* subspecies *stipitata* from Brazil and Peru and *E. stipitata* subspecies *sororia* from Peru. It probably originated in the western Amazon region and is primarily grown there as well as in Costa Rica. It is a perennial tree whose fruit is a juicy berry with bright yellow to orange skin containing bright, yellow flesh, which is fragrant but slightly fibrous and has an extremely sour taste (Arckoll 1991). They are climacteric fruit, and Hernández

Table 58 respiration rate of in milligram of carbon dioxide per kilogram per hour (source: adapted from Hernández and Fernández-Trujillo 2002)

Temperature (°C)	Pre-climacteric	Climacteric
10	40–323	601
13	60–337	861
20	140–310	1283

and Fernández-Trujillo (2002) gave their respiration rate in Table 58. Hernández and Fernández-Trujillo (2002) also reported that Arazá fruit had high acidity, mainly malate, followed by succinate, and to a lesser extent citrate, minerals, a moderate ascorbic acid content and low concentrations of reducing sugars.

Harvesting

Fruit are harvested when they reach optimum size but while still green (Arkcoll 1991, Hernández and Fernández-Trujillo 2002). If fruit are allowed to mature on the tree their shelf life is only about 3 days.

Storage

Arazá fruit are sensitive to chilling injury at temperatures below 12–13 °C. At 8–10 °C, fruit should be stored for less than 5 days to avoid chilling injury. Hernández and Fernández-Trujillo (2002) recommended 12–13 °C and 90–95% r.h. and showed that they could be kept in good condition for 2 weeks at 12 °C, 7 days at 10 °C and 5 days at 20 °C.

Modified atmosphere packaging

Hernández and Fernández-Trujillo (2002) reported that storage in LDPE bags reduced weight loss, shrivelling, development of skin scald, decay, softening and the loss of acidity but its effect varied between cultivars and was dependent on maturity. The steady state atmosphere in LDPE film bags was 5–6% CO₂ and 13% O₂ after 6 days at 10 °C. MA packaging with 5% O₂ + 5% CO₂ in 38 µm LDPE resulted in optimum quality maintenance, but if O₂ decreased to less than 2%, subsequent ripening could be irregular or inhibited when they were removed from the bags.

Disease

Hernández and Fernández-Trujillo (2002) and Arkcoll (1991) reported that the common diseases of

arazá fruit were anthracnose (*Gloeosporium album*) on wounds and associated with chilling injury and a rot caused by *Cylindrocladium scoparium* whose initial symptoms were small light brown lesions that developed to severe damaged areas that could penetrate about 0.3 cm into the pulp (Nuñez *et al.* 1995). Yeasts are a minor problem associated with fruit bruises (Hernández and Fernández-Trujillo 2002).

Babaco

Caricaceae

Carica × heilbornii nm *pentagona* (Heilborn) Badillo (Harman 1983). Babaco is not known in the wild and it has been suggested that it may be a hybrid possibly between the mountain papaya (*C. pubescens* (A. DC.) Solms-Laub. or *C. candamarcensis* Hook f.) and *C. stipulata*. It has also been referred to as *C. pentagonia* and *C. pentagona* Heilborn. Common names include mountain papaya and chamburo. Related species include papayuelo (*C. goudotiana*) orange papaya (*C. monoica*), toronchi (*C. pubescens*) and chamburro (*C. stipulata*). Hybrids of babaco and other *Carica* spp. also exist. It is presumed that it originated in the central south highlands of Ecuador and has been cultivated there since before the arrival of Europeans. It is grown commercially in New Zealand. The fruit is a fleshy berry oblong in shape with five grooves down the sides and blunt at the stem end and pointed at the distal end. They are up to 30 cm long and usually seedless or with only a few seeds. It is characteristically green and waxy as it develops and ripens to a yellow orange-coloured skin. The flesh is pale orange, succulent and juicy with a faint strawberry aroma and a low TSS content of about 6% when ripe (Morton 1987). The flavour is of a rather bland papaya (*C. papaya*). The milky sap from the fruit can cause skin irritation in some people.

Harvesting

The fruit turns from green to yellow during ripening (Figure 69). If the fruit is harvested when it is still green it may be possible to develop the fruit colour after harvest but not all the full flavour characteristic.



Figure 69 Harvest maturity of babaco is when the fruit have begun to turn yellow. See colour plate section.

Postharvest physiology

Harman (1983) found that the fruit were climacteric and respiration rate and ethylene production increased as the fruit ripened. In contrast Mencarelli *et al.* (1990) reported that ethylene production was relatively high at the first stage of fruit development, sharply decreased to undetectable levels along with the fruit size and increased again when around 40–50% of fruit surface has turned yellow.

Storage

Chilling injury was characterized by dark, sunken areas of skin, abnormal ripening, and increased susceptibility to fungal rots and occurred in storage below 3 °C (Harman 1983). Refrigerated storage recommendations include:

- 6 °C for 5 weeks with a subsequent shelf life of 1 week at 20 °C (Harman 1983).
- 10 °C and 90% r.h. for 5–6 weeks (green) (Snowdon 1990).
- 7 °C and 90% r.h. for 4 weeks (turning) (Snowdon 1990).
- 4 °C for 2 weeks with 1 week subsequently at 20 °C, but blotchy ripening can appear (Mencarelli *et al.* 1990).
- 8 °C for up to 3 weeks with 1 week at 20 °C but fruits were very soft (Mencarelli *et al.* 1990).
- 7.2 °C and 85–90% r.h. for 7–21 days (SeaLand 1991).

They could be stored at 4 °C for 2 weeks then 1 week at 20 °C but blotchy ripening could occur. In

storage at 8 °C for 2–3 weeks plus 1 week at 20 °C the fruits reached the full yellow colour but become extremely soft (Mencarelli *et al.* 1990). Fruit stored at 6 °C developed few rots and were of good quality after 5 weeks followed by a week at 20 °C, but fruit stored at 10 °C for 5 weeks ripened during storage and rapidly succumbed to fungal rots after transfer to 20 °C (Harman 1983).

Diseases

The main causal organisms of fruit rots were identified as *Phoma exigua* and *Colletotrichum acutatum* (Harman 1983).

Bael

Rutaceae

Aegle marmelos Correa. Chundawat (1990) reported that it is one of the oldest trees cultivated in India from prehistoric times. It has mythological and spiritual associations that may be related to its therapeutic value. It is also grown in the rest of the Indian sub-continent and Southeast Asia. He quoted the composition of the edible part of the fruit in India as 61.5 g water, 31.8 g carbohydrate, 1.8 g protein, 0.39 g fat, 1.7 g minerals, 55 mg carotene, 0.13 g thiamine, 1.19 mg riboflavin, 1.1 mg naicin and 0.8 mg vitamin C 100 g⁻¹ fresh weight. He also mentioned a report from Brazil that gave the vitamin C content as 65–100 mg 100 g⁻¹.

Bakuri

Guttiferae

Platonia insignis Mart., *Aristoclesia esculenta* Stuntz. The tree commonly grows wild in the Amazon region of northern Brazil and its distribution includes Paraguay, Colombia and Guyana.

The tree grows up to 25 m high with a pyramidal crown and yellow latex in the bark. The fruit is globular or ovoid, up to 12.5 cm wide, weighing up to about 900 g. The rind is yellow, hard, fleshy on the inside, 1–2 cm thick, and contains gummy, yellow, resinous latex. The white, pithy pulp, of pleasant odour and agreeable, subacid flavour, contains 1–4, rarely 5, seeds. The infertile seed compartments are

filled with pulp called *filho*, which is the part preferred (Morton 1987). She also gave the composition of the fruit in Table 58a.

Bakupari

Guttiferae

Rheedia brasiliensis Planch. & Triana also called bacuparyor bacoropary in Brazil and guapomo in Bolivia. The tree grows wild in the state of Rio de Janeiro in southeastern Brazil and Paraguay, but it is rarely cultivated. The ripe fruit is mostly used in making sweets or jam.

The tree is pyramidal like that of the bakuri but smaller; it is equally rich in yellow latex. The fruit is ovate, pointed at the apex, 4 cm long, with orange-yellow, pliable, leathery, tough skin, some 3 mm thick and easily removed. The aril-like pulp is white, translucent, soft, subacid, of excellent flavour, and encloses two rounded seeds (Morton 1987).

Banana

Musaceae

It probably originated in Southeast Asia and grows best in the humid lowland tropics within 30° of the equator. It is also grown commercially within the subtropics and at altitudes of 1000 m or higher in the tropics but growth is much slower and cropping is lighter (Von Loesecke 1950). Purseglove (1975) stated that all edible bananas, except Fe'i, are derived from *M. acuminata* Colla (*Musa* AA) and *M. bulbisiana* Colla (*Musa* BB). *M. acuminata* had its centre of diversity in the Melesian area where Simmonds (1962) reported that four of the five subspecies *malaccensis* (Ridl.) Simmonds, *microcarpa* (Beccari) Simmonds, *burmannica* Simmonds, and *siamea* Simmonds overlap. It is believed that the banana was probably one of the first foods that man cultivated. Robinson and Saúco (2010) reported that the earliest records of banana cultivation are from India some 2500 years ago. Imam and Akter (2011) reported that 'From its native south western Pacific home, the banana plant spread to India by about 600 BCE and later on it spread all over the tropical world. It is possibly the world's oldest cultivated crop. It even spread into the Islands of the Pacific

and to the west coast of Africa as early as 200–300 BCE'. Seed-bearing diploid ancestors of the modern banana can still be found in the Southeast Asia and the south western Pacific regions. It is thought that these wild ancestors hybridized naturally and some of these would have been parthenocarpic, triploid and sterile. Some would have edible fruit and local inhabitants discovered these and found that they could be propagated vegetatively so that banana cultivation originated (Robinson and Saúco 2010). Alexander the Great and his troops are believed to have found bananas growing in the valley of the Indus River as early as 326 BCE, during their abortive march through India trying to reach the Ocean. The first reference to bananas in Chinese literature comes from Yang Fu, an official dynasty at the end of the later Han Dynasty around the 2nd century CE. He used the names pa-chiao and kan-chiao. Pliny (around 67 CE) mentions that the fruit was the 'food of the sages'. The name of the genus, *Musa*, is from the Arabic name for the fruit. Avicenna mentions Mauz in an 11th century Arabic encyclopaedia. Mauz is also the Turkish and Persian name for banana. It is believed that the name banana is of African origin and was given by a tribe in the Congo. During the 1500s, as Spanish explorers began to visit the New World, the banana was taken with them. Friar Tomas de Berlanga is being claimed to have introduced the first banana plant to San Domingo in 1516. However, the view that bananas were found in the New World long before 1492 seems unlikely (Reynolds 1951). Actually there is a fossil in a museum in Villa de Leyva in Boyacá in Colombia that is claimed to be a banana fruit but it could be just a banana-shaped pebble. It seems unlikely that a soft banana fruit would have been fossilized. There was also some evidence of fossilized banana seeds in the Rocky Mountains in the United States but these were subsequently identified as belonging to the genus *Heliconia* (Reynolds 1951).

International trade in bananas has been carried out from time immemorial but its present scale dates back to the mid-to-late-19th century with shipments from the Caribbean Islands and Latin American countries to the United States. At that time banana bunches were loaded into vessels that were at first non-refrigerated and towards the turn of the century in refrigerated holds. These bunches are hung in ripening rooms and then in Britain each bunch was placed on wood wool in wooded returnable boxes for

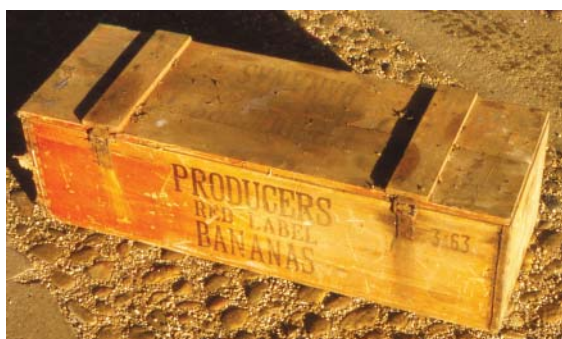


Figure 70 Wooded returnable box used for distribution of a single bunch of bananas from the ripening room to the retail market in United Kingdom in the 1950s. See colour plate section.

marketing. These boxes had 10 shillings and 6 pence return value on them (Figure 70), and the retailer cut the fingers or clusters of fingers from the bunch as the customer required.

Estimated world production has risen from just over 20 million tonnes in 1960 to well over 100 million tonnes in 2011. India is by far the largest producer (Table 59) and Ecuador the largest exporter (Table 60). Some countries, particularly those in Latin America, are very efficient banana producers with a good infrastructure and optimum inputs giving high yields. Many banana plantations in these countries are foreign owned. Many of the African Caribbean and Pacific (ACP) countries have economies that rely on tourism and banana exports, and because of factors such as comparatively higher labour costs or lower capital investment, they are unable to compete with other countries on banana price. Organic production and 'Fair Trade' are ways that many ACP

Table 60 The top 20 banana exporters in 2010 (source: adapted from FAO 2013)

Area	Quantity (tonnes)	Value (1000 \$)	Unit value (\$/tonne)
Ecuador	5,156,477	2,033,794	394
Belgium	1,219,139	1,236,919	1,015
Colombia	1,691,788	699,891	414
Costa Rica	1,836,206	672,050	366
USA	503,489	400,040	795
Germany	384,335	380,383	990
Guatemala	1,387,516	357,403	258
Philippines	1,590,066	319,296	201
Dominican Republic	306,301	250,456	818
France	322,479	242,216	751
Honduras	488,733	219,344	449
Côte d'Ivoire	335,593	135,492	404
The Netherlands	136,352	127,813	937
Cameroon	237,942	81,849	344
Mexico	176,152	72,440	411
Panama	271,468	64,600	238
Italy	69,821	61,193	876
Spain	56,701	54,000	952
Sweden	40,188	48,229	1,200
Brazil	139,540	45,269	324

countries have been able to supply niche markets. The World Trade Organization (WTO) ruling in 1997 against trade preferences between ACP countries and the European Union (EU) has been a potential problem in these fragile economies. The EU is the principle importer of bananas in the world, importing about half of the world banana exports. A settlement of the disputed WTO ruling over tariffs on imports into the EU was achieved in December 2009. The WTO brokered an agreement with the United States and the non-ACP banana producers that ACP suppliers can continue to export to the EU duty free and quota free under the 2008 EU Economic Partnership Agreements. The EU will continue to apply a duty on the import of non-ACP bananas called the Most Favoured Nations Duty. There are some provisos with the regulations but, in brief, they are that the non-ACP banana exports to Europe will attract progressively reducing tariffs starting at €148 tonne⁻¹ in 2010 and progressively falling to €114 tonne⁻¹ by 2017 when it is scheduled to end. It was reported on the BBC website (<http://www.bbc.co.uk/news/business-20263308>) on November 9, 2012, that the EU and Latin American countries signed an agreement to formally end

Table 59 Banana production in millions of tonnes per year (source: adapted from FAO 2013)

	2011	2010	2009	2008	2007	2006	2005
India	29.6	31.9	26.5	26.2	23.8	21.0	18.9
China	10.7	9.8	9.0	8.0	8.0	7.1	6.7
Philippines	9.2	9.1	9.0	8.7	7.1	7.0	6.7
Ecuador	7.4	7.9	7.6	7.0	7.5	6.1	6.1
Brazil	7.3	7.0	6.8	6.7	6.0	6.8	6.3
Indonesia	6.1	5.8	6.4	6.0	5.5	5.0	5.2
U.R. Tanzania	3.1	2.9	3.2	2.9	3.1	3.5	3.0
Guatemala	2.7	2.6	2.5	2.4	2.2	2.3	2.3
World	106.5	102.1	95.8	93.7	89.2	84.3	79.4

eight separate WTO cases. The head of the WTO, Pascal Lamy, was quoted 'After so many twists and turns, these complicated and politically contentious disputes can finally be put to bed. It has taken so long that quite a few people who worked on the cases, both in the secretariat and in member governments, have retired long ago'.

Over the 35 years from 1965 world production of bananas has increased almost 3.9 times from 26.4 million tonnes in 1965, 31.3 million tonnes in 1970, 36.7 million tonnes in 1980, 46.8 million tonnes in 1990 and 65.4 million tonnes in 2000 to 102.1 million tonnes in 2010 (FAO 2013).

Morphology and anatomy

Botanically the fruit is a parthenocarpic berry. The plant has a basal corm, the true stem, which has an apical meristem in the form of a flattened crown from which grow the spirally arranged leaves whose bases form a pseudostem. The flower is produced from the corm in the centre of the leaves and emerges at the top of the pseudostem. Only one flower is produced from one pseudostem. It takes about a month from formation to emergence of the inflorescence. The inflorescence is borne on a stout peduncle and consists of male and female flowers borne on nodes in two rows of nodal clusters with bracts in between. The top 5–15 nodal clusters produce female flowers and below this at the distal end, male flowers. There may be hermaphrodite flowers between the male and the female. The root system is adventitious with individual roots up to about 8 mm in diameter with primary roots producing thinner short lateral roots. They are white and fleshy later becoming somewhat corky and can spread up to 5 m laterally but mostly in the top 15 cm and to a depth restricted by the water table.

Desert bananas belong to the genus *Musa* section *Eumusa* where $2n=22$ chromosomes. A number of distinct groups of edible bananas have developed from species of *Musa*. The next, but much smaller, group is derived from members of the section *Callimusa* (previously classified as *Australimusa*) and is mainly restricted in importance to Polynesia. The Linnaean classification of 1783 gave the name *M. sapientium* L. to bananas that are eaten fresh and those that are cooked, for example plantains and cooking bananas, as *M. paradisiaca* L. Many authors

still use the Linnaean classification and many names have been used. However, Cheesman (1947–1949) defined the two species, *M. balbisiana* Colla and *M. acuminata* Colla, as the basis for almost all cultivated bananas and plantains. Simmonds and Shepherd (1955) and Stover and Simmonds (1987) confirmed this and reported that many desert varieties are derived from *M. acuminata*, some being diploid and a few being tetraploid but most being triploid. *M. balbisiana* has also contributed to the origin of desert bananas and plantains by hybridization with *M. acuminata*. These authors recommended that in place of the species name, an A genome or a B genome should be used showing the origin and contribution of the two species. Hence, a triploid variety whose origin is *M. acuminata*, e.g. the Giant Cavendish and Gros Michel varieties, would be referred to as *Musa* AAA. Where the triploid has one-third *M. balbisiana* and two-thirds *M. acuminata*, it would be referred to as *Musa* AAB. In addition, if there is a subgroup this should be included followed by the common name of the cultivar. For example *Musa* AAA (Cavendish subgroup) 'Robusta', *Musa* AA 'Pisang Mas' and *Musa* ABBB 'Kluai Teparod'. The term variety is a unit of classification that is a subdivision of species. It may apply loosely to a number of groups within a species. Cultivated varieties of a plant produced in horticulture are called cultivars. Varieties usually have a Latin name, while cultivars are in the local language. In some definitions a cultivar is a plant that is cultivated and is not found in nature. In this definition all the cultivars from the Cavendish subgroup would be varieties since they all have been selected from somatic mutations in commercial production not from banana breeding. Goldfinger, *Musa* AAAB, that has been bred for production would be a cultivar.

No such nomenclature system has been developed for bananas derived from section *Callimusa* where $2n=20$ chromosomes. This group is known as Fe'i bananas and there are numerous varieties of this group in the South Pacific region. They are very distinctive plants with upright fruit bunches usually with bright orange flesh. They are cooked before being eaten. Fe'i bananas are probably mainly derived from *Musa maclayi* F.Muell. ex Mikl.-Maclay although their origins are not well understood and it would be unwise to assume that other *Callimusa* have also not been significant (Stover and Simmonds 1987).

Cultivars can be named, for example, as *Musa* (Fe'i group) 'Utafun'.

Since the edible varieties are parthenocarpic and often female or male sterile, seeds are rarely found in their fruit, which has made it difficult to improve them by conventional breeding. Almost all varieties used commercially have arisen from mutations selected in the field. Gros Michel was the fruit that dominated the international trade from its beginnings in the mid-19th century until the late 1940s. It is a tall heavy bearing variety but is susceptible to Panama disease (*Fusarium* root rot) caused by the fungus *Fusarium oxysporum* f. sp. *cubense*. It was reported as early as 1928 in Trinidad that there was concern about the susceptibility of Gros Michel to Panama disease. In the coffee zones of Colombia Gros Michel is still grown commercially and is locally preferred to Cavendish and achieves a higher price on the local market. Gros Michel is also grown in parts of Thailand and receives a high price when exported to Japan. Three races of Panama disease have been described that can affect bananas. Race 1 caused the epidemics on Gros Michel and also affects some other varieties and tetraploids. Race 2 affects cooking bananas e.g. bluggoe and some tetraploids while race 4 affects races 1 and 2 susceptible varieties as well as the Cavendish varieties. Race 4 has been shown to consist of sub-tropical and tropical races. The tropical race 4 can attack unstressed plants while the sub-tropical race 4 usually only attacks when plants are in a stressed condition.

Giant Cavendish has been the main group of varieties in international trade since the late 1940s and selections include Grand Naine, Lacatan, Poyo/Robusta, Valery and Williams, which are largely distinguished from each other by the height of the pseudostem. The tallest is Lacatan (up to 5.5 m) followed by Robusta and Giant Cavendish (up to 5 m), and the smallest is the Dwarf Cavendish (1.2–2.1 m). In addition Dwarf Cavendish is tolerant to a wide range of climates including cool conditions. Grand Naine responds well to optimum growing conditions but does not grow or yield well in sub-optimum conditions including soils with low fertility or insufficient rainfall or irrigation. The Sucrier/Pisang Mas/Honey varieties are very sweet and have small fruit, thin skin, yellowish flesh and small bunches (up to about 13 kg). Plants are up to 3.5 m high, prefer light shade and are not well

adapted to cooler temperatures. They take about 11 months from planting the suckers to the bunch being sufficiently mature for harvesting. Potential yield is lower than Cavendish. In St Lucia it was reported by farmers to yield about half as much.

Breeding programmes have developed tetraploid bananas and plantains, starting in 1922 at the Imperial College of Tropical Agriculture in Trinidad. This programme was subsequently transferred to establish the banana breeding programme at Bodles in Jamaica (producing Bodles Altafort, which is *Musa* AAAA). Other breeding programmes include the Centro Nacional de Pesquisa de Mandioca e Fruticultura Tropical that was established in Brazil and the Fundacion Hondureña de Investigacion Agrícola (FHIA) that was originally established at a research station of the United Fruit Company in Honduras. These programmes have largely concentrated in breeding tetraploids. However, there is concern about the tetraploids possessing the B genome. This is because the banana streak virus (BSV) is integrated in the B genome and may be activated, especially if they are exposed to stress or are propagated *in vitro* by tissue culture. FHIA-21 (*Musa* AAAB) cooking banana with plantain in its pedigree is reported to be resistant to Black Sigatoka disease, and total fingers per bunch and bunch weights at maturity are about double those of False Horn plantain. They have higher fruit moisture content and a softer ripe texture than False Horn. FHIA-01, also called Goldfinger (*Musa* AAAB), is a desert banana that has been bred to be high yielding and resistant to Black Sigatoka; however, this resistance has been questioned. Goldfinger was registered as a patent in 1994 (US Patent PP08983). Seberry and Harris (1998) showed that Goldfinger harvested at 36–39 mm grade had an adequate green life. Ripening at 16 °C with greater than 96% r.h. in 1 ppm ethylene gave fruit of the best appearance and colour and had longer shelf life after ripening than Williams, but Goldfinger fruit softened more rapidly than Williams or Lady's Finger (*Musa* AAB). It has not replaced the Cavendish varieties in international trade as was hoped.

The source of probably all the varieties of banana and plantain currently cultivated has originated from somatic mutations that have been recognized in the field by growers who see some advantage in them. They select and propagate them. Bananas are very susceptible to somatic mutations especially if they are

propagated *in vitro* by tissue culture. In Jamaica in the 1970s it was decided to plant large areas of former sugar cane land with bananas. This was a change from the traditional mainly small farmer production. They also decided at that time to change the variety from Lacatan, Valery and Robusta to Grand Naine. In order to do this 80 plants were taken from Honduras to a biotechnology company in Florida, and these were used to produce the thousands of tissue-cultured plants needed. When these were planted in Jamaica it was found that a high proportion, perhaps 20%, had mutated and largely produced undesirable characteristics. It was subsequently established that the probability that mutations will occur depends on the position on the plant from which the tissue is taken for propagation. If they are taken from the corm meristem, then the chances of mutation are very low.

Varieties in international trade

In 1402 Portuguese colonists took banana plants from Guinea to the Canary Islands. In 1826 Charles Telfair obtained Cavendish plants from south China and took them to Mauritius. In 1829 some plants were sent to England. In 1834 the 6th Duke of Devonshire wrote to the Chaplain at Alton Towers: 'My Dear Sir, A thousand thanks for the banana, it arrived quite safe and I am delighted to have an opportunity of seeing that most beautiful and curious fruit. It is the admiration of everybody and has been feasted upon at dinner today according to the directions.' The Duke eventually obtained plants at Chatsworth House, which is the seat of the Dukes of Devonshire. Their family name is Cavendish and the Duke named it *Musa cavendishii*. Joseph Paxton was their head gardener who cultivated the bananas and got them to produce fruit in a conservatory at Chatsworth. A few years later the Duke supplied two cases of plants to a missionary named John Williams, destined for Samoa. Only one *Musa cavendishii* survived the journey and that single specimen was the forebear of bananas that flourish in Samoa and other South Sea Islands. Probably in 1853 some plants were received from Chatsworth, and although they were in poor condition some survived and distributed among the islands. Also the first banana plant from Chatsworth may also have been the origin of stock introduced to the Canaries in 1855 (Anonymous 2012). Apparently suckers were sent to the West Indies.

Gros Michel was the variety first used in international trade. It has long been grown in South East Asia and Sri Lanka. Jean Francois Pouyat, a French botanist and chemist, who settled in Jamaica in 1820 probably introduced it. He brought the fruit from Martinique to his coffee estate perhaps to diversify his production. It was originally called Banana Pouyat, then later this became the Martinique Banana and finally Gros Michel. It is called Hom Thong in Thailand. The Agricultural Society in Jamaica awarded Pouyat a doubloon for introducing such a valuable variety (Von Loesecke 1950, Davies 1990).

Chemistry and nutritional value

Bananas are mainly ripened and eaten fresh but are also used in cooking. Amyl esters give bananas their distinctive flavour and aroma and butyl esters give them a fruity flavour and aroma, but other esters, aldehydes, alcohols and ketones have been associated with flavour and their production rates can increase during ripening (Tressl and Jennings 1972). McCarthy *et al.* (1963) also claimed that amyl esters gave bananas their distinctive flavour and aroma and butyl esters gave them a fruity flavour and aroma.

Within a cultivar, there is large plant-to-plant variation and within plant variation in nutrient composition for fruit harvested from the same field (Shewfelt 1990). Forster *et al.* (2002) showed that there were differences in the chemical compositions of the bananas from Tenerife and Ecuador. Also there were clear differences in the chemical composition of the bananas from Tenerife according to the cultivation method (greenhouse and outdoors), farming method (conventional and organic) and region of production (north and south). They found that the cultivar did not influence the chemical composition, except for insoluble fibre content. Lee (2008) reported that an average-sized banana had 450–467 mg potassium. Bananas are also high in fibre and a medium-sized banana has about 6 g of fibre. They contain vitamins. Wall (2006) reported that bananas contained higher concentrations of lutein than provitamin A pigments, α -carotene and β -carotene. She also showed that different varieties of bananas could contain different levels of nutrients. In Hawai'i Apple bananas had almost three times more vitamin C (12.7 mg 100 g⁻¹ fresh weight) than Williams (4.5 mg 100 g⁻¹) and Apple bananas had an average of 96.9 μ g β -carotene

Table 61 The composition of banana fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	74.91 g	Thiamine	0.031 mg
Energy	89 kcal	Riboflavin	0.073 mg
Protein	1.09 g	Niacin	0.665 mg
Total lipid (fat)	0.33 g	Vitamin B-6	0.367 mg
Carbohydrate, by difference	22.84 g	Folate	20 µg DFE
Fibre, total dietary	2.6 g	Vitamin B-12	0.00 µg
Total sugars	12.23 g	Vitamin A	3 µg RAE
Calcium	5 mg	Vitamin A	64 IU
Iron	0.26 mg	Vitamin E (α-tocopherol)	0.10 mg
Magnesium	27 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	22 mg	Vitamin D	0 IU
Potassium	358 mg	Vitamin K (phylloquinone)	0.5 µg
Sodium	1 mg	Fatty acids, total saturated	0.112 g
Zinc	0.15 mg	Fatty acids, total monounsaturated	0.032 g
Total ascorbic acid	8.7 mg	Fatty acids, total polyunsaturated	0.073 g

and 104.9 µg α-carotene 100 g⁻¹, whereas Williams averaged 55.7 µg β-carotene and 84.0 µg α-carotene 100 g⁻¹. Apple bananas also had higher P, Ca, Mg, Mn and Zn concentrations than Williams. The chemical content was given by USDA (2012) in Table 61.

Carbohydrates

Starch accumulates during maturation and in the preclimacteric phase there is little change in the principal carbohydrate metabolites (Wardlaw *et al.* 1939a). Starch is converted into sucrose, glucose and fructose during ripening. In dessert bananas ripening involves a reduction in starch content from around 15–25% to less than 5% in the ripe pulp, coupled with a rise of similar magnitude in total sugars (Barnell 1943, Desai and Deshpande 1975, Lizada *et al.* 1990). During the early part of ripening sucrose is the predominant sugar, but in the later stage glucose and fructose were predominant (Barnell 1943). Hubbard *et al.* 1990 also reported that the proportion of the different sugars was related to the stage in the respiratory climacteric of the fruit. They also showed that starch was broken down into sucrose by the action of sucrose phosphate synthetase and non-reducing sugars from sucrose by acid hydrolysis. The onset of the starch–sugar conversion has been shown to be influenced by harvest maturity, with more mature fruits responding earlier. These changes have been demonstrated in both triploid (*Musa AAA*) (Madamba *et al.* 1977) and diploid (*Musa AA*) fruit (Montenegro 1988). In bananas the breakdown of starch is usually completed during ripening, but in

plantains this breakdown is not complete even when the fruit is fully yellow and soft (George 1981). In Apple bananas (*Musa AA*) the fruit still had residual starch when it was fully yellow and they may need to be ripened further before being eaten (Wei and Thompson 1993). At temperatures at or below 12 °C starch was no longer converted into sugar (Wardlaw *et al.* 1939a). Arora *et al.* (2008) reported that the cultivar Karpooravalli is rich in carbohydrate content in terms of total starch (1786.0 µg g⁻¹ dry weight in the peel and 544.85 µg g⁻¹ dry weight in the pulp) and sugars (53.53 µg g⁻¹ dry weight in the peel and 39.05 µg g⁻¹ dry weight in the pulp).

Protein

Toledo *et al.* (2012) found that chitinases were the most abundant types of proteins in unripe bananas. Two isoforms in the ripe fruit were implicated in their stress/defence response and three heat shock proteins and isoflavone reductase were also abundant at the climacteric stage. Pectate lyase, malate dehydrogenase and starch phosphorylase accumulated during ripening. In addition to the ethylene formation enzyme amino cyclo carboxylic acid oxidase, the accumulation of *S*-adenosyl-L-homocysteine hydrolase was needed because of the increased ethylene synthesis and DNA methylation that occurred in ripening bananas.

Phenols

Banana fruits can contain high levels of phenolic compounds especially in the peel (Von Loesecke

1929). Tannins are perhaps the most important phenolic from the point of view of fruit utilization because they can give fruit an astringent taste. As fruit ripens their astringency becomes lower which seems to be associated with a change in structure of the tannins, rather than a reduction in their levels, in that they form polymers (von Loesecke 1950, Palmer 1971). Mura and Tanimura (2003) also reported loss of astringency during ripening of bananas and found that it was by the polymerizing of polyphenol compounds with a molecular weight of 2×10^5 . Phenolics are also responsible for the oxidative browning reaction when the pulp of fruit (especially immature fruit) is cut. The enzyme polyphenoloxidase is responsible for this reaction (Palmer 1971).

Acids

Bananas and plantains, like most other fruits, are acid with a pulp pH below 4.5 (Von Loesecke 1950). Palmer (1971) showed that the main acids in bananas were ascorbic, citric, malic and oxalic and the levels of these acids normally increase during ripening. TA in the pulp was shown to increase rapidly from about 28 to 67 ml sodium hydroxide 100 g^{-1} fresh weight from the preclimacteric minimum to the climacteric and then it slowly declined postclimacteric to about 52 ml sodium hydroxide 100 g^{-1} fresh weight (Wardlaw *et al.* 1939a). These measurements were carried out on Gros Michel at 29.4°C and 85% r.h. over a ripening period of 14 days.

Vitamin C

Wall (2006) reported that the average vitamin C content of Dwarf Brazilian (*Musa* AAB 'Santa Catarina Prata') was almost three times higher ($12.7 \text{ mg } 100 \text{ g}^{-1}$) than the vitamin C content of Williams (*Musa* AAA Cavendish subgroup), which was $4.5 \text{ mg } 100 \text{ g}^{-1}$. About 100 g of Dwarf Brazilian bananas would provide 14–17% of the US daily requirements for vitamin C for the average adult. These results agree with Wenkam (1990), who reported vitamin C values of $5.1 \text{ mg } 100 \text{ g}^{-1}$ for Williams and $14.6 \text{ mg } 100 \text{ g}^{-1}$ for Dwarf Brazilian. The vitamin C levels for Cavendish based on high-performance liquid chromatography ranged from 2.1 to $18.7 \text{ mg } 100 \text{ g}^{-1}$ (Leong and Shui 2002, USDA 2012, Vanderslice *et al.* 1990, Wills *et al.* 1984a). Wills *et al.* (1984b) detected 1.4 mg dehydroascorbic acid 100 g^{-1} using UV-vis at 214 nm but Wills *et al.* (1984a) did not detect any

dehydroascorbic acid in bananas even at 214 nm wavelength. Vanderslice *et al.* (1990) measured 3.3 mg dehydroascorbic acid 100 g^{-1} in bananas using fluorometric detection. Wills *et al.* (1990) reported that Sugar bananas (*Musa* AAB) had higher vitamin C, starch, glucose, fructose and dietary fibre than Cavendish fruit. Wall (2006) reported the following analysis: vitamin C $12.7 \text{ mg } 100 \text{ g}^{-1}$, vitamin A $12.4 \text{ mg RAE } 100 \text{ g}^{-1}$, total soluble solids 17.9% and moisture 68.5% for Dwarf Brazil. For Williams she reported: vitamin C $4.5 \text{ mg } 100 \text{ g}^{-1}$, vitamin A $8.2 \text{ mg RAE } 100 \text{ g}^{-1}$, soluble solids 20.5% and moisture 73.8%. The average vitamin C content of Dwarf Brazilian fruit ranged from 6.3 to $17.5 \text{ mg } 100 \text{ g}^{-1}$ and Williams ranged from 2.5 to $6.3 \text{ mg } 100 \text{ g}^{-1}$ from four locations in Hawai'i. Ascorbic acid content can decrease during ripening (Wenkam 1990). Ascorbic acid content of Dwarf Cavendish, Rasabale and Rajabale increased during ripening at 20°C for 21 days and then decreased slightly up to 35 days (Desai and Deshpande 1975).

Carotenoids and vitamin A

Vitamin A is an organic compound that has a major contribution in human health. It plays an important role in vision, cell growth and the regulation of the immune system. Similar to other vitamins, it cannot be synthesized in sufficient quantities by the body and must be obtained from the diet. Plants do not contain vitamin A but they have carotenoids. Some carotenoids can be converted into vitamin A during human digestion and are called provitamin A carotenoids (pVACs). In meat retinol is the main form of vitamin A. Measurement of pVAC is commonly related to retinol activity equivalent (RAE). The RAE is a relatively new unit for expressing vitamin A activity. One microgram of RAE is equivalent to 1 mcg of all-*trans*-retinol, 12 mcg of all-*trans*-beta-carotene or 24 mcg of other provitamin A carotenoids. RAE is therefore a unit used for quantifying the vitamin A value of sources of vitamin A, including both preformed retinoids in animal foods and precursor carotenoids in plant foods. It is defined as 3.3 International Units of vitamin A.

Wall (2006) reported that bananas are generally thought to be low in pVAC, but some Fe'i bananas with yellow or orange pulp have been shown to have relatively high levels of carotenoids. In ripe bananas, the major carotenoids were lutein and carotene.

Dwarf Brazilian bananas had 96.9 mg β -carotene and 104.9 mg α -carotene 100 g^{-1} , whereas Williams averaged 55.7 mg β -carotene and 84.0 mg α -carotene 100 g^{-1} . She also reported that bananas contained higher concentrations of lutein than provitamin A pigments. Average lutein concentrations were 154.9 mg 100 g^{-1} for Dwarf Brazilian and 108.3 mg 100 g^{-1} for Williams. In Hawai'i, Apple bananas had an average of 96.9 μg β -carotene and 104.9 μg α -carotene 100 g^{-1} , whereas Williams bananas averaged 55.7 μg β -carotene and 84.0 μg α -carotene 100 g^{-1} .

In bananas most carotenoids are in the peel with generally low amounts in the pulp. Seymour (1985) found that the carotenoid content of banana peel could change during ripening depending on temperature. Those ripened at 35°C had significantly increased carotenoids in the peel, while in those at 20°C carotenoids remained constant. The typical yellow colour of ripe banana peel is developed purely because of the breakdown of chlorophyll, which masks the yellow colour in unripe bananas. At high temperature, the fruit remains greenish in spite of carotenoid synthesis because chlorophyll content is only partially reduced. Wenkam (1990) also found that the level of carotenoids increased during maturation and ripening. These results confirm those of Von Loesecke (1929) and contradict those of Gross and Flugel (1982) who found a decrease in carotenoids during the initial phase of ripening of bananas.

In the early 2000s, the late Lois Englberger found that some orange-fleshed bananas, indigenous to the Pacific region, had high levels of pVACs. Moderate to high levels have since been measured in other cultivars. Studies of some orange-fleshed cultivars indigenous to the Pacific region had high levels of pVACs (Englberger *et al.* 2006). Measurement of the pVAC in 171 cultivars showed that levels varied from undetectable in some fruit with white cream pulp to $3500\text{ }\mu\text{g}$ 100 g^{-1} (or 211 n mol g^{-1} dry weight) fresh weight for those with more orange-coloured pulp (Davey *et al.* 2009, Pereira *et al.* 2011). The group that had the most cultivars with yellow-orange pulp was the Fe'i bananas. At 863 n mol g^{-1} dry weight, Utin Iap is the cultivar with the highest level of pVACs ever measured in a banana. Bananas with high pVACs levels appear to have been from *Musa acuminata* ssp. *banksii*, or an *Australimusa* (*Callimusa*) species, and all appear to have originated in the New Guinea

area (Pereira *et al.* 2011). These included African plantains, Pacific plantains and *Musa* AA cultivars from Papua New Guinea. Bunch morphology also seems to be related to levels of pVACs, with bunches that are oriented in such a way that they receive more light having the highest levels (Davey *et al.* 2007). In a study of some Micronesian cultivars, those with the highest pVACs content consistently also had 75–100% of all-*trans*-beta-carotene. The only other carotenoid species consistently detected in fruit pulp extracts are small amounts of lutein and a few unidentified minor compounds (Englberger *et al.* 2003). The pVACs content of Hawai'i's Dwarf Brazilian ranged from 7.7 to 17.1 mg RAE 100 g^{-1} . Variability in the maturity of Dwarf Brazilian bananas contributed to the wide range of pVACs values. However, this variability reflects a range that can be expected in commercially harvested fruit. Wenkam (1990) reported 4.1 mg RAE (49.2 mg β -carotene 100 g^{-1}) for Dwarf Brazilian bananas, which falls below the range of values given by Wall (2006). For most of the Dwarf Brazilian bananas, α -carotene levels were equal to or greater than β -carotene concentrations, which illustrates the importance of separating and quantifying all the vitamin A pigments for accurate nutritional information. β -Carotene is the most active pVAC in banana and α -carotene less active (Wall 2006). In a comparison between some Indian banana varieties, Arora *et al.* (2008) reported that the cultivar Karpooravalli showed the maximum carotenoid content in the peel ($68\text{ }\mu\text{g g}^{-1}$ d.w.) while being the second highest in β -carotene content ($143.12\text{ }\mu\text{g}$ per 100 g). However, Red Banana ranked highest in total carotenoid content of pulp ($4\text{ }\mu\text{g g}^{-1}$ dry weight), and β -carotene was estimated to be the highest in the peel ($241.91\text{ }\mu\text{g}$ per 100 g) and in pulp ($117.2\text{ }\mu\text{g}$ per 100 g). In studies where β - and α -carotenes were quantified, Cavendish fruit had 2.6, 5.3 or 8.7 mg RAE 100 g^{-1} (Hart and Scott 1995, Muller 1997). The USDA National Nutrient Database (USDA 2012) lists 3 mg RAE 100 g^{-1} for Cavendish bananas. Wall (2006) reported the vitamin A content as 12.4 mg RAE 100 g^{-1} . She also reported that Williams, harvested from four locations in Hawai'i, had 8.2 mg RAE 100 g^{-1} for vitamin A and ranged from 6.1 to 9.3 mg RAE 100 g^{-1} . This was higher than the 4.5 mg RAE 100 g^{-1} reported by Wenkam (1990) for Cavendish.

Other phytochemicals

A phytochemical is a natural bioactive compound found in plant food that works with nutrients and dietary fibre to protect against disease. Imam and Akter (2011) in their phytochemical and pharmacological review gave the following phytochemicals in various parts of bananas and plantains:

- catecholamines such as norepinephrine, serotonin and dopamine;
- tryptophan, indole compounds;
- pectin in the pulp;
- flavonoids and related compounds (leucocyanidin, quercetin and its 3-O-galactoside, 3-O-glucoside and 3-O-rhamnosyl glucoside) from the unripe pulp of plantain;
- serotonin, norepinephrine, tryptophan, indole compounds, tannin, starch, iron, crystallizable and non-crystallizable sugars, vitamin C, B-vitamins, albuminoids, fats and mineral salts in the fruit pulp;
- acyl steryl glycosides such as sitoindoside-I, sitoindoside-II, sitoindoside-III, sitoindoside-IV and steryl glycosides such as sitosterol gentiobioside and sitosterol *myo*-inosityl- β -D-glucoside;
- a bicyclic diarylheptanoid, *rel*-(3*S*,4*aR*,10*bR*)-8-hydroxy-3-(4-hydroxyphenyl)-9-methoxy-4*a*,5,6,10*b*-tetrahydro-3*H*-naphtho[2,1-*b*]pyran, and 1,2-dihydro-1,2,3-trihydroxy-9-(4-methoxyphenyl)-phenalene, hydroxyanigorufone, 2-(4-hydroxyphenyl)naphthalic anhydride and 1,7-bis(4-hydroxyphenyl)hepta-4(*E*),6(*E*)-dien-3-one;
- several triterpenes such as cyclomusalenol, cyclomusalenone, 24-methylenecycloartanol, stigmast-7-methylenecycloartanol, stigmast-7-en-3-ol, lanosterol and β -amyrin;
- an antihypertensive principle, 7, 8-dihydroxy-3-methylisochroman-4-one from the fruit peel;
- cycloartane triterpenes such as 3-epicycloeucalenol, 3-epicyclomusalenol, 24-methylenepolinastanone, 28-norcyclomusalenone and 24-oxo-29-norcyclartanone have been isolated from the fruit peel;
- cellulose, hemicelluloses, arginine, aspartic acid, glutamic acid, leucine, valine, phenylalanine and threonine have been isolated from pulp and peel;
- hemiterpenoid glucoside (1,1-dimethylallyl alcohol), syringin, (6*S*, 9*R*)-roseoside, benzyl alcohol glucoside and (24*R*)-4*α*,14 α ,24-trimethyl-

Sacholesta-8,25(27)-dien-3 β -ol have been isolated from the flower.

Minerals

Bananas have a high potassium content, and K is reported to be essential for keeping human blood pressure normal and also helps in proper functioning of the heart. Lee (2008) reported that an average-sized banana had 450–467 mg K. The average K content of Hawai'i's bananas (Dwarf Brazilian and Williams) was 330.6 mg 100 g⁻¹ fresh weight, and Mg content averaged 35.1 mg 100 g⁻¹. Iron, copper and manganese are other minerals of nutritional importance in bananas (Wall 2006). Hardisson *et al.* (2001) reported that for bananas grown in Tenerife there was 5.09 mg g⁻¹ K, 0.59 mg g⁻¹ P, 0.38 mg g⁻¹ Ca and 0.38 mg g⁻¹ Mg on a fresh weight basis. In Nigeria, Adeyemi and Oladiji (2009) gave the following for different stages of ripeness:

- Unripe 73.47% ash, 0.68% Zn, 0.146% Mn and 0.506% Co.
- Ripe 77.19% ash, 0.80% Zn, 0.271% Mn and 0.886% Co.
- Over-ripe 79.22% ash, 0.78% Zn, 0.118% Mn and 0.756% Co.

Changes in mineral content during postharvest ripening must be related to the changes in mass of the fruit through water loss and to a lesser extent through mass losses due to respiration. Wall (2006) reported that Apple bananas also had higher P, Ca, Mg, Mn and Zn concentrations than Williams.

Preharvest factors

Bunch covers

Plastic film covers are usually put over bunches soon after they emerge from the top of the pseudostem. This is to protect the fruit particularly from damage by insects particularly thrips. After harvest the green life of the covered bunches was 1 or 2 days longer than the ones that had no covers. This was probably because the decision to harvest was based on the degree of rounding of the individual fruit fingers. Since the fruits under the covers were not exposed to the environment, they lost less water and had a higher moisture content, which gave the appearance of being fully mature (Johns and Scott 1989). Choudhury *et al.* (1996) reported a longer green life for covered Dwarf

Cavendish fruits, whereas Parmar and Chundawat (1984) reported a reduction in green life using a blue polyethylene cover with the variety Basarai. The fruits grown under a cover lost more weight after being harvested than those not covered. They attributed this to be probably as a consequence of going from a higher to a lower humidity environment. Parmar and Chundawat (1984), on the contrary, recorded lower postharvest weight losses in fruits that had been covered. With regard to quality, the covered fruits, except for those under non-transparent covers, had a higher total soluble solids content than those not covered. The conjectured that this was probably because the higher temperature under the cover favoured the conversion of starch into sugars. The reduction in the content of total soluble solids in fruits grown under non-transparent covers might be due to the higher moisture content of these fruits and the presence of 'hard lumps' probably due to the lack of conversion of starch into sugars. The sugar-to-acid ratio of the covered fruits was also higher than those not covered.

Growing conditions

Growing conditions can also affect postharvest characteristics. Chillet and de Lapeyre de Bellaire (2002) found a weak correlation between the manganese concentration and wound ethylene production in lowland bananas in the West Indies. They also showed that in the wet season lowland fruit was more fragile and produced more wound ethylene than highland fruit. In Thailand Williams and Grand Naine grown under low chemical production, systems tended to have higher levels of sugars and acids but were softer and there was some indication that they contained less starch than those from a conventional production system (Ambuko *et al.* 2006). In a survey of fruit quality of Philippine bananas from non-chemical production, the problems highlighted all related to management practices and none to the effects of organic production on postharvest aspects (Alvindhia *et al.* 2000). However, in Britain Nyanjage *et al.* (2000) found that imported organically grown Robusta bananas ripened faster at 22–25 °C than non-organically grown bananas as measured by peel colour change, but ripe fruit had similar total soluble solids levels from both production systems. The peel of non-organic fruits had higher nitrogen and lower phosphorus contents than organic fruits. Chillet *et al.* (2010) reported that in Guadeloupe wound

anthracnose, caused by *C. musae*, and early ripening are the main problems affecting the quality of export bananas. This problem is generally with bananas harvested in lowland plantations during the rainy season. They found that stressful growing conditions, especially soil flooding, slowed fruit growth but had no direct effect on fruit susceptibility to *C. musae* or on their green life. However, fruit that had been exposed to prolonged lower temperatures were less susceptible to wound anthracnose. They also found that bananas of the same grade but different physiological ages had markedly different susceptibility to *C. musae*. Srikul and Turner (1995) reported that larger fruit and the application of high levels of nitrogen fertilizer resulted in a shorter green life as did low irrigation. Marriott *et al.* (1979) found that there were differences in preclimacteric life of bananas between different varieties and also the temperature during fruit growth affected their green life.

Harvest maturity

Ahmed *et al.* (2001) found very strong evidence that in Robusta the fruit had much better organoleptic properties the more mature they were when harvested. However, if bananas are allowed to mature fully before harvest and harvesting is shortly after rainfall or irrigation, the fruit can easily split during handling operations, allowing microorganism infection and postharvest rotting (Thompson and Burden 1995). Muchui *et al.* (2010a, 2010b) studied the cultivars Grande Naine and Williams in Central Kenya to establish the best harvest maturity indices. Bunches were allowed to grow until half, three quarter and full maturity. They found that the bunch age and finger diameter were highly positively correlated for both varieties. Also finger diameter was correlated positively with pulp to peel ratio and total soluble solids.

Angularity

Determination of the maturity stage of bananas by visual inspection of the fullness of the fingers is one of the most commonly used methods. As bananas mature on the plant they increase in size and width and they become less angular and more rounded in cross section. The final degree of roundness varies between cultivars, but it is a reasonably precise method and, with experience, is practical to use, especially for small-scale growers. Although farmers generally know and commonly use this method, it is

not always applied in practice. In some countries farmers harvest less mature fruit, even for local markets, because they have cash flow problems and they harvest as soon as the ripening room operator will accept the fruit (Thompson 1981).

Calliper grade

The width of individual fingers can be used to determine their harvest maturity. The maturity of hands in the bunch varies slightly. Those at the proximal end of the bunch are more mature than those at the distal end, so usually a predetermined finger from the bunch is used and its maximum width is measured with callipers, hence it is referred to as the *calliper grade*. In the Windward Islands the middle finger on the second hand from the top is used for calliper grade. The length of the same finger may also be measured for the same purpose. Simple templates have been developed to facilitate farmers in judging calliper grade including those made from plastic (Figure 71) or metal (Figure 72). These latter can be mounted on poles in order to use on bunches that are out of reach. The cross-sectional angle is also used to describe harvest maturity. The definitions of the 'angularity' vary but in the West Indies light $\frac{3}{4}$, $\frac{3}{4}$, full $\frac{3}{4}$, heavy full $\frac{3}{4}$ and full have all been used. They correspond approximately to 37–41 mm for light $\frac{3}{4}$, 41–45 mm for $\frac{3}{4}$ and over 45 mm diameter (von Loesecke 1950, Stover and Simmonds 1987). Various terms are used in producer countries to classify the angularity of the fruit and the marketing agents for export companies require farmers to harvest only a particular grade. The mean finger weights of Gros Michel were 145 g with a pulp:peel ratio of 1.30 for heavy full $\frac{3}{4}$ stage and 117 g with a pulp:peel ratio of 1.17 for full $\frac{3}{4}$ stage. Full $\frac{3}{4}$ was reached in 80–90 days. The time between harvest and the onset of ripening at 11.7 °C was 2 or 3 days for heavy full $\frac{3}{4}$ and within 14 days for full $\frac{3}{4}$ (Gane 1952).

Ribbon tagging

For export of bananas, harvest maturity must be very precise and so the time after the flower shoot appears in each plant is recorded. At anthesis a plastic cover was placed over the bunch to protect the fruit as it is developing. In order to identify exactly when anthesis occurred a coloured plastic ribbon is attached to the bunch, hence the process was called ribbon tagging.

The same colour is used for 1 week throughout the plantation (or even for the whole country or group of countries in the Windward Islands) and changed to another colour the following week and so on. This meant at the harvest time the age of each bunch is precisely known. Wilson Wijeratnum *et al.* (1993) showed that the Ambul variety grown in Sri Lanka reached physiological maturity 8–9 weeks after anthesis. For Giant Cavendish in Ecuador the maximum time from anthesis to harvest was usually 12 weeks and in the Windward Islands it was 13 weeks.

Physiological age

Jullien *et al.* (2008) found that the best method of measuring the preclimacteric postharvest life of bananas is their physiological age, expressed as a sum of accumulated temperatures from flowering to harvest, rather than in days. Practices such as removing the male bud and trimming the false hands can accelerate the fruit pulp filling rate, which in turn can reduce the time needed for them to reach a sufficient commercial grade (Krauss and Johanson 2000). However, since these practices are commonly carried out at all commercial plantations in one area, the effect of these practices has already been factored in.

Harvest operations

Harvesting practices vary between countries, size of operation and objectives. In many countries the bunches are harvested, loaded on to lorries and padded with banana leaves for transport to markets and ripening rooms (Figure 73). Field dehanging and manual transfer of hands to the packhouse and overhead cableways for transporting bunches to the packhouse are two methods. Dehanging of bananas is the



Figure 71 Plastic template for measuring calliper grade of bananas.

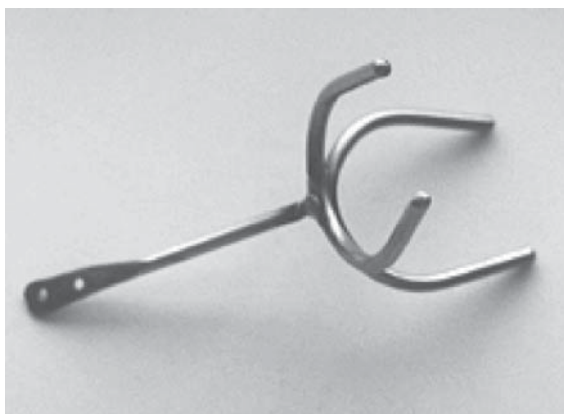


Figure 72 Metal template that is attached to a pole for measuring calliper grade of bananas.

cutting of the hands of fruit from the main bunch stem. This involves cutting through the crescent-like pad of tissue that attaches the hand to the main stem. The cut surface exudes latex for sometime after dehanding and is also liable to infection by fungi that can cause crown rot.

Field boxes

Field dehanding of bananas into specially designed plastic field boxes was developed in the Windward Islands during the early 1970s, mainly in response to the high level of damage suffered when bunches of fruit were moved from the field to the packhouse. This damage occurred to a greater or lesser extent with all growers but was particularly serious in



Figure 73 Banana transport in Eritrea in 2013. See colour plate section.

bananas harvested from small mountainside farms. The technique involves dehanding bunches, either while still attached to the pseudostem or when they were cut and hung from a frame beside the plant. The former method was more effective in reducing damage, but the latter was easier in practice (Thompson and Burden 1995).

Field dehanding

Field dehanding method varies but in the Windward Islands it starts with placing two clean banana leaves flat on the ground with their mid-ribs facing upwards. The pseudostem is partly cut so the bunch can be pulled down and each hand is cut off with a piece of stalk attached starting from the bottom of the bunch and working upwards and the hands of fruit are placed on banana leaves. Considerable skill is required in cutting the crowns evenly and selecting only the clusters that are suitable for the market. The hands are cut into clusters of four to eight fingers the crowns are trimmed neatly and they are left for some 10 min on the leaf to allow the latex to stop draining. Any cluster not reaching the required standard should be rejected at this point. They are commonly left behind as a mulch together with the leaves and chopped up pseudostem. There is no evidence that this practice results in a pool of fungal spores that might increase disease. The polyethylene film sleeving that was used to protect the bunches is placed in at least a double layer at the bottom of a plastic packing tray as padding to protect the clusters from damage. The clusters are placed in the tray with the crowns downwards; inter-laying each row with at least a double layer of polyethylene between each row of clusters should be carried out. The clusters should not be placed on top of each other in the tray. The tray full of clusters is then carried to the field packhouse on the head of the worker.

Overhead cableways

The most successful method of minimizing damage while transporting bunches from the plant to the packing station is by overhead cableways. The bunches are joined together in trains by 1.2 m long spacing rods, which reduce damage to the fruit by preventing the swinging bunches from striking each other. The trains of bunches can be pulled to the packhouse manually, by a small tractor or a donkey. Some plantations have used a suspended motor hanging on

the cableways to haul bunches but this method is not common, possibly because there is heavy wear on the driving pulleys and the cable. The layout of the cableways is based on a regular shaped planting of bananas with a centrally located packing station. It involves a central primary cableway running the length of the plantation with secondary lateral branches serving the whole plot. These secondary branches are ideally spaced 100 m apart so that harvesters need carry bunches no more than 50 m to hang them on the rolling hooks. Bunches are brought right to the dehanging site still suspended from the rolling hook on which they were placed when harvested.

This method has been applied for several decades in areas of large-scale banana production in Latin America and elsewhere. The cableways involve high capital investment to install and maintain, and its viability depends on the use of a high yielding production system. For successful operation the cableway must be included in the original planning of the plantation, so that its layout can be co-ordinated with other features such as drainage ditches, irrigation, roads and packing station location. The topography of the land is important with a slope of less than 0.2%, especially for the lateral branches, where it will be difficult to restrain the train of rolling hooks for bunches to be attached. The cableway remains in place for the life of the planting. A version of this type of cableway, including modifications to recover bananas from hillsides, was designed for use in the Windward Islands (Kemp and Matthews 1977). The overhead cable was a single strand high tensile steel wire suspended about 2.25 m above ground from arches fabricated from galvanised pipe. The cableway served as a runway for roller conveyor hooks, from which bunches of fruit were suspended. The rolling hooks carrying bunches from the field to packing station are made up into trains totalling up to 30 bunches (Figure 28).

Trailers

In Martinique and Guadeloupe bunches are placed on padded shelves in trailers which are parked alongside the plantation. When full the trailers are towed by a tractor to the packhouse. In a study in Jamaica in 1971 several experiments were carried out on reducing damage including wrapping the bunches in soft plastic padding. Bunches were also stacked horizontally in lorries padded with banana leaves. It was

found that almost all damage caused to the fruit occurred during the loading and unloading operations but padding bunches before harvest controlled this but was impractical and costly (Stamford *et al.* 1971). Transporting bunches from the field to the packhouse balanced on the heads of workers resulted in 1.1% of fingers with severe scarring and 0.4% with severe neck damage. Where bunches were transported by lorries padded with banana leaves, for 9 miles 7.1% of fingers had severe scarring and 15.1% had severe neck damage. Where bunches were transported by lorries padded with banana leaves, for 45 miles 25.1% of fingers had severe scarring and 12.2% had severe neck damage. In subsequent experiments it was determined that most of the damage occurred during loading and unloading the bunches (Stamford *et al.* 1971).

Case studies

Yemen

In the former Peoples Democratic Republic of Yemen 90% of production was in the Abyan Governorate mainly in the Hadramout. Banana production was almost exclusively on state farms. Harvesting was carried out daily between 7:00 and 10:00 AM. Harvest maturity was subjectively based on angularity of the fruit and bunches were cut from the plant and stacked at the roadside where a lorry passed at intervals and bunches are loaded into the back up to three bunches deep. When the lorry was full it was taken to an open sided packhouse on the farm where the hands were cut from the bunches and placed in plastic boxes with 10 kg of fruit in each box. The plastic boxes used were the nest/stack type 59.5 cm long × 39 cm wide × 21.5 cm deep and had good ventilation but were generally handled badly so that many were broken and could not be stacked properly or protect the bananas in transit. The boxes were then stacked onto lorries, eight or nine boxes high depending on the size of the lorry, for transport to Aden to a ripening room where they arrived between 4:00 and 5:00 PM the same afternoon (Thompson 1985). Recorded losses were high (Table 62) but the quality of the fruit from the ripening rooms was very low with much of the peel blackened and even the pulp bruised. The director who estimated them to be nearer 25% considered the official estimates of postharvest losses low.

Table 62 Production, in tonnes, and postharvest losses of bananas in the Peoples Democratic Republic of Yemen

1980–1981		1981–1982		1982–1983	
Production	Losses (%)	Production	Losses (%)	Production	Losses (%)
9165	17.0	9122	11.7	9274	11.1

Department of Statistics and Planning, PDYR.

Sudan

In a study of banana transport in the Sudan it was shown that bunches packed in lorries padded with banana leaves and transported from the field to the ripening rooms had extremely high levels of damage. Thompson and Silvis (1974) compared transporting the fruit as bunches with dehanding from the plant and packing them in wooden boxes for transport in the Sudan. They found in seven trials that there were 16% of fingers with neck damage for those transported as bunches and only 4% for those transported in boxes. In other trials where bananas were transported from Kassala to Khartoum, bruising was reduced by packing bunches in cotton bags or reduced even more by field dehanding into wooden boxes (Table 63). At that time transport for people from Wad Ramli and Kassala to Khartoum was infrequent and comparatively expensive. So it was common for people to travel sitting on the tops of the bananas, often quite a lot of people on one lorry. Cosmetic losses can be illustrated by a study of banana quality in the Sudan. A quality assessment was carried out on bananas as they were being removed from commercial ripening rooms. On the basis of European quality standards 95% of the fruit were considered unmarketable (Silvis and Thompson 1974). Indeed, if they had been in Europe this would have represented a physical loss of 95%. However, in the Sudan the demand for bananas was greater than the supply and people were happy to pay the same price for the fruit whatever their condition (Silvis *et al.* 1976).

Packing

Where cableways are used the hands are cut from the bunch while it is still suspended from the cable and the hands are placed directly into water to prevent latex staining. When dehanding, the crown should be

Table 63 The effects of packing materials for commercial transport from Kassala to Khartoum a distance of 560 km (source: adapted from Thompson and Silvis 1974)

	Bunches with no protection	Bunches in cotton bags	Field dehanding into wooden boxes
No bruising	0.0	7.1	41.4
Light bruising	1.1	10.3	32.8
Medium bruising	4.3	26.5	18.3
Sever bruising	94.6	56.1	7.5
Neck damage	72.3	19.4	0.6

evenly cut close to the main stem of the bunch leaving as much as possible of the crown attached to the hand, otherwise its outer fingers may be detached during subsequent handling and it can affect the development of crown rot. The design of the knife or chisel used for dehanding varies considerably in different countries, but in all cases the tool must be very sharp to give a clean smooth cut in a single movement. As soon as the hands of fruit are removed from the bunch they are placed in the wash tank to remove dirt and latex, which exudes from the cut surface of the crown. There should be a flow of water through the tank to avoid the accumulation of dirt and fungal spores that may infect the crown. At the packing plant, an inspector checks for minimum finger length, calliper grade and different types of damage. Any cluster below standard is rejected. Fungicide is commonly applied in a cascade. The crowns should be uppermost since they are the part most susceptible to attack.

It is important to keep the packhouse clean and remove stalks, rejected fruit and bunch stalks that might contaminate the packhouse air (Krauss and Johanson 2000). Tanks containing alum (potassium aluminium sulphate at 10 g L⁻¹) used for delatexing and tanks of fungicide may be used in field packhouses and sometimes in large packhouses where flowing water is not available.

In packing fruit for export most exporters use polyethylene film liners inside the cartons to help reduce moisture loss from the bananas and provide some protection from damage during handling and transport. They are commonly 12.5 μ thick and 110 mm wide $\times$ 130–135 mm long. However, this procedure can vary with different producers and the distance the bananas are to be transported. Some fold sheets of polyethylene around the fruit; others pack

all the box contents in a sealed bag under partial vacuum, and a few use individual small bags, each containing a single cluster of fruit. Vacuum packing is commonly used where the transport time is long because it can modify the CO₂ and O₂ levels around the fruit, which is said to extend their green life. The final handling of the bananas in the packing station involves packing the hands in the boxes in which they are to be marketed. Since the 1960s virtually all bananas exported outside their production region have been packed in fibreboard boxes. For export a standard full telescopic 40 lb (18.14 kg) carton is used although a 33 lb (15 kg) carton is sometimes used. The 40 lb carton measures 586 mm long × 377 mm wide × 207 mm high for the base and 595 mm long × 387 mm wide × 209 mm high for the cover and is made of corrugated fibreboard. Usually a perforated inner liner is placed between the carton base and the polyethylene film to provide additional protection.

Export cartons

In early 1970s in the Windward Islands the hands were packed directly into fibreboard boxes in the field ready for export. This was only achieved when the problems of latex staining of the fruit and crown rot were overcome. These problems were normally dealt with by washing the hands and treating them with chemicals at the packhouse. In the field they were both controlled by first laying the hands crown downwards on banana leaves to prevent the latex getting on to the fruit and placing a pad of absorbent paper impregnated with alum (potassium aluminium sulphate) and fungicide (thiabendazole or benomyl) on the cut crown directly after dehanding. This helps to coagulate the latex to prevent it staining the fingers and prevented crown rot becoming established. An additional problem associated with field dehanding and packing was infestation of boxed fruit by insects, mainly cockroaches and ants. Where this is a problem it has been dealt with by fumigation of the boxed fruit with the broad-spectrum insecticide permethrin, usually during ripening in the importing country (Thompson and Burden 1995). Although this method became established practice with many growers and resulted in an increase in the percentage of top quality fruit marketed it was abandoned. Challenges with this method included keeping the cartons clean and dry and importing countries rejected it.

Modified atmosphere packaging

There are many reports of the positive effects of modified atmosphere packaging on different varieties of banana in different films from different countries including Chauhan *et al.* (2006), Shorter *et al.* (1987), Satyan *et al.* (1992), Tiangco *et al.* (1987), Tongdee (1988), Abdullah and Pantastico (1990), Wei and Thompson (1993), Marchal and Nolin (1990) and Chamara *et al.* (2000). However, Wills (1990) mentioned that an unsuitable selection of packaging materials can accelerate the ripening of fruits or enhance CO₂ injury when ethylene accumulated.

Modified atmosphere packaging is very commonly used in various forms in the banana industry. One example is where individual clusters of six fingers are packed in small polyethylene film bags, which are then packed together into a large carton. These are transported by sea freight then ripened and marketed while still in the same bags. Banavac® is a patented system which uses large 0.04-mm-thick polyethylene film bags in which typically 18.14 kg of green bananas are packed, then a vacuum is applied and the bags are sealed and transported in cartons (Badran 1969). Nair and Tung (1988) reported that Pisang Mas bananas had an extension in their postharvest life of 4–6 weeks at 17 °C when they were stored in evacuated collapsed polyethylene film bags by applying a vacuum not exceeding 300 mm Hg. Scott *et al.* (1971) found that the storage life of bananas in polyethylene bags was extended for 6 days longer than non-wrapped fruit at 20 °C. In a subsequent trial, bananas were packed in 13.6 kg commercial packs inside polyethylene film bags. During 48 h transport in Australia the fruit could be kept in good conditions at ambient temperatures and then be held in a commercial ripening room for several days, and still had a low weight loss, good flavour and nice appearance when subsequently ripened. Latundan bananas (*Musa* AAB) can be stored in 0.08-mm-thick polyethylene bags at ambient temperature of 26–30 °C for up to 13 days and Lakatan bananas (*Musa* AA) on the other hand, shown a lag of 3 days before colour break down upon exposure to air (Abdullah and Pantastico 1990). Tiangco *et al.* (1987) also observed that green life of Saba bananas (*Musa* BBB) held in modified atmosphere packaging at ambient temperature had a considerable extension of storage life. Tongdee (1988) found that the green life of Klui Khai fruits (*Musa* AA) could be

maintained for more than 45 days in polyethylene bags at 13 °C. This was longer by more than 20 days compared to the fruits stored at 25 °C in polyethylene bags.

Ahmad and Thompson (2007) tested the effect of modified atmosphere packaging on the ripening and quality of ripe fruit. Bananas ripened in 0.05 mm of polyethylene bags had an extended 5 days shelf life, slower the rate of softening and a more attractive fresh appearance than those not in plastic bags. Panellists preferred the bananas ripened in polyethylene bags to those not in polyethylene bags because of their better flavour and appearance. In separate experiments it was observed that effectiveness of ethylene in hastening ripening was not reduced with CO₂ levels of less than 5% and O₂ levels of greater than 10%. Bowden (1993) showed that the effect on yellowing of bananas that had been initiated to ripen was related to the thickness of plastic and therefore the gas composition within the film (Figure 74). Film thickness also affected weight loss. For example at 13 °C Wei and Thompson (1993) showed that weight loss of Apple bananas after 4 weeks storage in PE film was 1.5% in

50 µm, 1.8% in 37.5 µm and 2.1% in 25 µm while fruit stored without packaging was 12.2%.

Potassium permanganate

Including potassium permanganate inside the bags can increase the positive effects of modified atmosphere packaging (Chamara *et al.* 2000), as does gas flushing (Chauhan *et al.* 2006) and some other chemicals (Ranasinghe *et al.* 2005). Satyan *et al.* (1992) stored Williams bananas in 0.1-mm-thick polyethylene tubes at 13, 20 and 28 °C and found that their storage life was increased 2–3 times compared to unwrapped fruit. Where potassium permanganate was included in the tube the increase in storage life was 3–4 times compared to non-wrapped fruit. Fruits sealed in polyethylene tubes with ethylene absorbents could be stored for 6 weeks at 20 or 28 °C and 16 weeks at 13 °C.

Storage

Temperature

Bananas suffer from chilling injury that is proportional to the time they are exposed to chilling

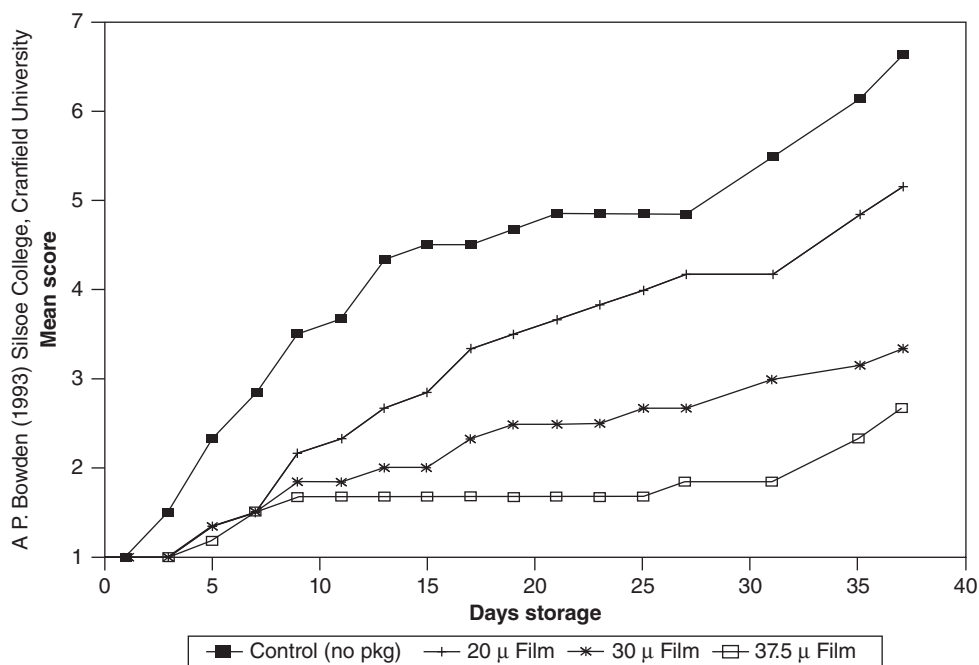


Figure 74 Changes in skin colour, where 1 = dark green and 6 = fully yellow, of five finger clusters of Apple bananas stored at 13 °C in different thickness of polyethylene film bags. (Source: Bowden 1993. Reproduced with permission of Cranfield University.)

temperatures. Recommended storage temperatures are essentially the minimum temperature that can be used before chilling injury occurs. However, chilling injury is time as well as temperature dependent that is why some authorities give maximum time or a journey time. Recommendations for storage of green bananas include the following:

Cavendish

- 12.8–14.4 °C with 85–90% r.h. (Pantastico 1975);
- 13–14 °C (Thompson and Burden 1995);
- 14 °C for Grand Naine (Robinson and Saúco 2010).

Dwarf Cavendish

- 11.5–11.7 °C (Wardlaw 1937).

Gros Michel

- 11.5–11.7 °C (Wardlaw 1937);
- 11.7 °C (Hardenburg *et al.* 1990).

Lacatan

- 14–14.4 °C (Wardlaw 1937).

Latundan

- 14.4–15.6 with 85–90% r.h. for 3–4 weeks (Pantastico 1975).

Non-specified varieties

- 13 °C (Purseglove 1975);
- 12.8–15.6 °C with 85–90% r.h. for 4 weeks (Pantastico 1975);
- 12–14 °C and 90–95% r.h. for 2–3 weeks (Mercantilia 1989);
- 13 °C and 85–90% r.h. for 10–20 days (Mercantilia 1989);
- 13 °C and 85–90% r.h. for 10–20 days (Snowdon 1990);
- 13–15 °C and 85–90% r.h. for 1 month (Snowdon 1990);
- 13.3–14.4 °C and 90–95% r.h. for all cultivars except Gros Michel, which is 11.7 °C (Hardenburg *et al.* 1990);
- 14.4 °C and 85–95% r.h. for 7–28 days (SeaLand 1991);
- 12–14 °C and 85–95% r.h. for 15 days for green mature fruits (Tchango *et al.* 1999).

Simmonds (1966) gave the following temperatures to be used for transporting Cavendish fruit by sea freight: 11.7 °C for transport from Tropical

America and West Africa to Europe and the United States, 12.2 °C for transport from Trinidad to Britain, 11.4 °C for transport from West Africa to Europe, 13.1 °C for transport from Jamaica to Britain and 11.1–11.7 °C for Robusta/Poyo for transport from Samoa to New Zealand.

For bananas that have been initiated to ripen 13 °C for 3–6 days (Mercantilia 1989), 20 °C for 1–2 days (Mercantilia 1989) or 13–15 °C and 85–90% r.h. for 5–10 days (Snowdon 1990). 10 °C and 85–90% r.h. for green fruit for 5 weeks with 6% loss (Pantastico 1975), 7.2–10 °C and 85–90% r.h. for ripe fruit for 10 days (Pantastico 1975).

Humidity

Storage humidity was shown by Wardlaw and Leonard (1940) to affect respiration rate of Gros Michel bananas in that at 29.4 °C the climacteric was earlier for those in 100% r.h. compared to those in 70% r.h. (Figure 75). In experiments it was shown that plantains stored in cartons without a packing material lost weight rapidly during ripening and became blackened and shrivelled. Those packed in dry coir dust lost less weight and those in moist coir dust gained weight; no shrivelling was seen following the latter two treatments and there was less skin blackening (Table 75). The fruits in coir dust remained green for long periods before ripening rapidly (Thompson *et al.* 1974). However, they took up moisture and would eventually split if stored for too long.

Water deficit in plant tissues may stimulate ethylene production, and as a consequence there can be an increase of tissue respiration (Yang and Pratt 1978). Exposing fruit postharvest to low humidity may also result in sufficient stress to the fruit to initiate ripening. This was shown by Thompson *et al.* (1974) for plantains (Table 64).

Littmann (1972) found that water stress decreased the preclimacteric life of Giant Cavendish bananas and showed a depression in the climacteric peak of respiration. Finger *et al.* (1995) reported that fresh mass loss of 5% and higher promoted shortening of the preclimacteric life of bananas and induced a decrease of maximum rates of respiration and ethylene production during climacteric ripening. Preclimacteric ethylene production was stimulated by water stress. Fruit with a mass loss of 20% ripened abnormally with a decreased pulp softening and

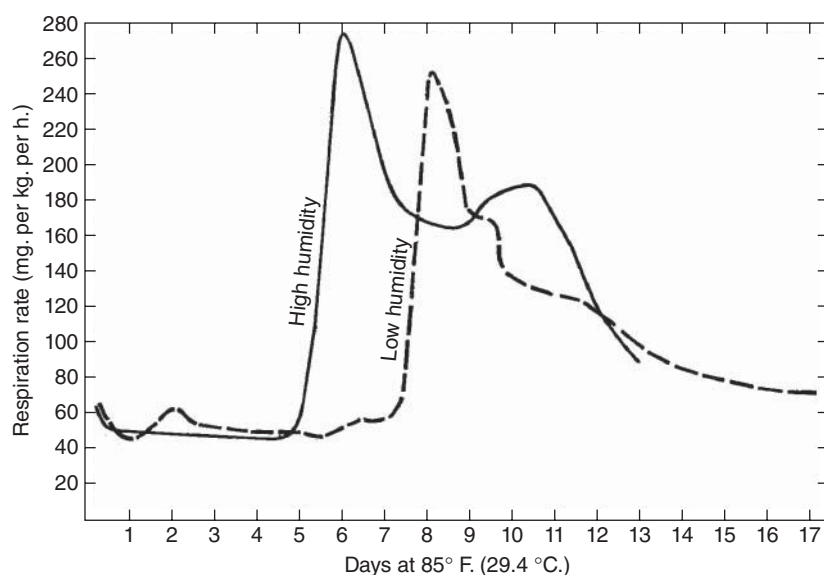


Figure 75 Effects of humidity on ripening of Gros Michel bananas. (Source: Wardlaw and Leonard 1940.)

Table 64 The effects of the humidity of the incoming air in a flow-through system on the ripening of freshly harvested plantains in ambient conditions (23–33 °C) in Jamaica

	Colour score	Weight loss (%)	Total soluble solids	Pulp : peel ratio	Penetrometer force	Skin:pulp
100% r.h.	2.3	0.9	10.6	1.9	12.0	6.6
0% r.h.	7.0	18.4	24.9	3.5	8.2	1.8

Penetrometer force was the force required to inject a Magness and Taylor pressure tester (Thompson *et al.* 1972a,b).

excessive brown colour of skin. Akkaravessapong *et al.* (1992) examined the effect of approximately 50, 70 and 90% r.h. on the susceptibility of bananas to mechanical damage from 2 days after harvesting until 5 days after ripening had been initiated. Humidity did not influence susceptibility to mechanical injury, the tissues damaged at 50% r.h. dried to a black colour while those damaged at 90% r.h. remained light brown. George and Marriott (1982) found that in plantains an increase of weight loss of 0.5% per day resulting from low storage humidity was typically accompanied by a decrease of 65% in the potential storage life. They also found that treatment with gibberellin extended the preclimacteric period when subsequent storage was under high humidity (unstressed conditions) but had no effect under low humidity (water-stressed conditions). Ullah *et al.* (2006) observed that high humidity delayed the

ripening of bananas and consequently increased their shelf life. Storage of bananas submerged in water delayed the climacteric phase of bananas in a similar way to controlled atmosphere storage but they did not complete their ripening processes properly. Water storage resulted in splitting of bananas because of excessive intake of water. Microbial spoilage of water-stored bananas emerged as serious problem against successful application of this technology. Reduced dissolution of O₂ into water affected the ripening process, and in order to attain the best quality and increased shelf life, water storage was found to be not suitable for banana fruit but storage in 100% r.h. showed better results.

The effects of polyethylene film wraps on the postharvest life of fruits may also be related to moisture conservation around the fruit as well as the change in the CO₂ and O₂ content. This was shown by

Table 65 Effects of wrapping and packing material on ripening and weight loss of plantains stored at tropical ambient conditions of 26–34 °C and 52–87% r.h. (source: adapted from Thompson *et al.* 1972a,b)

Packing material	Days to ripeness	Weight loss at ripeness
Not wrapped	15.8	17.0%
Paper	18.9	17.9%
Moist coir fibre	27.2	(3.5%) ^a
Perforated polyethylene	26.5	7.2%
Polyethylene	36.1	2.6%
LSD ($p = 0.05$)	7.28	2.81

^aThe fruit actually gained in weight.

Thompson *et al.* (1972a, 1972b) for plantains where fruit stored in moist coir or perforated polyethylene film bags had a longer storage life than fruits that had been stored unwrapped. But there was an added effect when fruits were stored in non-perforated bags, which was presumably due to the effects of the changes in the CO₂ and O₂ levels (Table 65). So the positive effects of storage of fresh preclimacteric fruits in sealed plastic films may be, in certain cases, a combination of its effects on the CO₂ and O₂ content within the fruit and the maintenance of high moisture content. The effect of moisture content is more likely to be a reduction in stress of the fruit that may be caused by a rapid rate of water loss in non-wrapped fruit. This in turn may result in increased ethylene production to internal threshold levels that can initiate ripening.

1-MCP

Exposure of harvested plant material to 1-MCP, which is 1-methylcyclopropene, has been shown to reduce ethylene production of fruits, vegetables and flowers. de Wild (2001) even suggested that short-term controlled atmosphere storage might be replaced by 1-MCP treatment. During storage at 15 °C and 90% r.h. the respiration rate of bananas was reduced by treatment with 200 ppb for 12 h 1-MCP especially when applied before they were initiated to ripen with ethylene. 1-MCP maintained the bananas at the green stage while the control bananas turned yellow (Martino *et al.* 2010).

Many researches have reported an extension in the preclimacteric life of bananas that had been treated with 1-MCP postharvest. Williams *et al.* (2003) found that at 15 °C bananas could be stored for 6 weeks in CA, but was doubled by application

of 300 nl L⁻¹ 1-MCP for 24 h at 22 °C directly after ripening initiation with ethylene. However, 3 nl L⁻¹ had no effect and 30 µl L⁻¹ slowed ripening 'excessively'. Eating quality was not affected by 300 nl L⁻¹ 1-MCP (Klieber *et al.* 2003). With Cavendish bananas treatment with 1-MCP delayed peel colour change and fruit softening, extended shelf life and reduced respiration rate and ethylene production (Jiang *et al.* 1999). Ripening was delayed when fruits were exposed to 0.01–1.0 µl L⁻¹ 1-MCP for 24 h and increasing concentrations of 1-MCP were generally more effective for longer periods of time. Similar results were obtained with fruits sealed in 0.03-mm-thick PE bags containing 1-MCP at either 0.5 or 1.0 µl L⁻¹, but delays in ripening were longer at about 58 days. Jiang *et al.* (2004) working on the cultivar Zhonggang found that fruits treated with 1-MCP for 24 h at 20 °C significantly delayed the peaks of respiration rate and ethylene production but did not reduce the peak height of those exposed to 50 ml L⁻¹ ethylene. They also found a reduction in all the changes associated with ripening. The 1-MCP effects on all these changes were higher during low-temperature storage and reduced in high-temperature storage. Green mature Apple bananas were treated with 1-MCP at 0, 50, 100, 150 and 200 nl L⁻¹ for 12 h and then stored at room temperature of 20 ± 1 °C and 80 ± 5% r.h. A total of 50 nl L⁻¹ 1-MCP was the best in extending the shelf life based on total sugars, soluble pectins, firmness and external appearance in the end of storage. The 50 nl L⁻¹ 1-MCP delayed the onset of peel colour change by 8 days while 100, 150 and 200 nl L⁻¹ 1-MCP by 10 days compared to non-treated (Pineiro *et al.* 2005). Khai were treated with 1-MCP at 50, 100 and 250 ppb for 24 h then stored at 20 °C. 1-MCP delayed ripening and prolonged storage to some 20 days with the higher concentration being more effective, but bananas treated with 250 ppb 1-MCP had the lowest respiration rate and ethylene production. However, there is no significant difference among treatments for colour changes (Jansathorn and Kanlayanarat 2006). Boonyariththongchai and Kanlayanarat (2010) treated Kluai Khai (*Musa AA*) with 100, 200, 400 and 600 ppb of 1-MCP at 25 °C for 24 h then transferred them to 13 °C for storage. The 1-MCP-treated fruit had delayed colour change and an extended storage life of 30 days while non-treated fruit had only 20 days storage life. Fruits

treated with 1-MCP at 100–600 ppb had a lower respiration rate and ethylene production, while 600 ppb 1-MCP had the lowest respiration rate and ethylene production. 1-MCP maintained fruit firmness better than those not treated. Moradinezhad *et al.* (2010) showed that on Williams exposed to 100 ml L⁻¹ for two days to initiate ripening the subsequent application of 1-MCP 300 nl⁻¹ for 24 h at 22 °C extended their shelf life and also improve fruit quality during storage at 16, 19, 22 or 25 °C.

Some negative effects have also been shown on bananas treated with 1-MCP including uneven degreening of the peel. Pelayo *et al.* (2003) that under the conditions they tested the efficacy of 1-MCP in delaying ripening of partially ripened bananas was inconsistent for commercial application. In some experiments, bananas at ripeness stage 3 or 4 that were treated with 1000 nl L⁻¹ 1-MCP at 20 °C for 6 or 24 h had higher ethylene production rates but respiration rates were reduced and changes in skin colour and flesh firmness were delayed without negative impacts on the qualitative or quantitative aroma composition of the fruit. However, similar 1-MCP treatments were much less effective in retarding ripening of stage 3 or 4 bananas in subsequent experiments. de Martino *et al.* (2007) working on Williams that had been initiated to ripen found that peel degreening was delayed after the 1-MCP treatment and there was some general browning throughout the peel in both the green and yellow areas of the ripening peel. Exposure of banana fruit to millilitre per litre 1-MCP slowed ripening and also enhanced the chilling injury accelerated the occurrence of chilling injury-associated increased membrane permeability (Jiang *et al.* 2004).

Joyce *et al.* (1999) found that banana ripening induced by propylene could be delayed by exposure to 15 ml⁻¹ L⁻¹ of 1-MCP at 20 °C for 12 h. However, the 1-MCP treatment was less effective as propylene-induced ripening progressed, although it was able to maintain the eating-ripe condition of fruits for a longer time than the control treatment. Similarly, Yueming *et al.* (1999) found that 1-MCP applied in a concentration range 0.01–10 ml⁻¹ L⁻¹ at 20 °C for 12 h after 1 day of ethylene treatment slowed the ripening of bananas, but it was ineffective when applied 3 or 5 days after ethylene treatment. De Martino *et al.* (2007) initiated Williams to ripen by exposure to 200 µl L⁻¹ of ethylene for 24 h at 20 °C.

These bananas were then treated with 200 nl L⁻¹ 1-MCP at 20 °C for 24 h and then stored in greater than 99.9% N₂ + less than 0.1% O₂ in perforated plastic bags at 20 °C. No differences in the accumulation of acetaldehyde and ethanol were detected during storage compared to fruits not treated with 1-MCP. Peel degreening, the decrease in chlorophyll content and chlorophyll fluorescence were delayed after the 1-MCP treatment. There was some general browning throughout the 1-MCP-treated peel in both the green and yellow areas of the ripening peel. They concluded that it appears the 1-MCP-treated peel 24 h after the ethylene treatment may still undertake some normal senescence that occurs during banana ripening.

Coatings

Fruit are dipped or sprayed with a range of materials postharvest to improve their appearance or delay deterioration. Banks (1984) described a coating called Tal Prolong, which consisted of sucrose esters of fatty acids and carboxy methylcellulose. It was claimed that it could delay the ripening of bananas. He postulated that the effect was due to the restriction in gas exchange between the fruit and its surrounding atmosphere. This caused a build up of CO₂ and a depletion of O₂ thus causing an effect achieved in controlled atmosphere storage. Bancroft (1989) showed some reduction in levels of disease on stored apples coated with Tal Prolong. Banana crowns coated with Semperfresh also showed delayed development of crown rot caused by infection with *Colletotrichum musae*. However, when fruits were inoculated with *C. musae* after harvest the results were inconsistent (Thompson *et al.* 1992). The control of crown rot could be enhanced by the inclusion of organic acids to the coating material (Al Zaemey *et al.* 1993). The company who manufactured and marketed Semperfresh was called Surface Systems International. In 1992 and 1993 they brought out a range of different formulations for different purposes. Ban-seel® was a liquid formulation to protect and extend the storage life of bananas and plantains. Banana crowns coated with Semperfresh (sucrose esters of fatty acids and carboxy methylcellulose) showed delayed development of crown rot and this effect could be enhanced by the inclusion of organic acids to the coating material (Al Zaemey *et al.* 1989). Maqbool *et al.* (2011) applied a composite coating of 10% gum Arabic plus 1.0% chitosan to

bananas postharvest. They showed that after 33 days storage coated fruit had 24% lower weight loss and 54% lower total soluble solids than those not coated and they were firmer, had higher total carbohydrates and reducing sugars than those not coated.

Irradiation

UV-C irradiation extended postharvest shelf life of banana by delaying chlorophyll degradation, because of the inhibition of chlorophyllase and peroxidase activities, and reduced ethylene production and respiration rate compared to those that had not been irradiated (Pongprasert *et al.* 2011). They also noted that it was possible that UV-C at 0.03 kJ m^{-1} may alleviate chilling injury symptom. Also these results imply that UV-C could play a role in activation of plant defence mechanisms and antioxidant systems, assisting in reducing chilling stress (Pongprasert *et al.* 2009). Previously Marriott and Palmer (1980) had reported that UV irradiation in bananas resulted in peel damage that reduced its potential for postharvest control of pathogens. Although dosages of around 0.5 kGy can extend banana green life but irradiation can alter the banana peel; the maximum dose tolerated by the fruits is likely around 0.5 kGy.

Cold shock

Xu *et al.* (2002) investigated the effect of cold shock treatment on postharvest softening of Baxi bananas. They found that exposure to air at -2°C for $2\frac{1}{2}$ h significantly delayed fruit softening. Cold shock treatment inhibited the activities of polygalacturonase and amylase and delayed the degradations of pectin and starch that resulted in a delay in fruit softening. However, cold shock treatment did not affect the pectinesterase activity that decreased gradually during fruiting softening. There was no mention of chilling injury.

Controlled atmosphere storage

In early work on controlled atmosphere work on bananas, Kidd and West (1933) found that storage in 2.5 and 5.0% O_2 did not materially decrease the rate of ripening. However, Gane (1936) observed a suppression of the climacteric and reduction of respiratory activity in an atmosphere of 10% CO_2 and 10% O_2 . Leonard (1947) observed a reduction in the respiration rate of fruit stored in O_2 concentrations lower

than air and had no effect in concentrations higher than air. Wardlaw (1940) subjected unripe bananas to different combinations of O_2 and CO_2 in a closed system and concluded that there was up to 50 times reduction in rate of respiration over a wide range of O_2 and CO_2 concentrations as compared with air. Young and Biale (1962) reported that in an atmosphere of 10% CO_2 combined with 10% O_2 extended of storage life of bananas. There are very wide variations in recommendations for optimum the CA conditions for bananas (Thompson 2010) and perhaps it would be safe to use 3% O_2 + 5% CO_2 at 14°C . In some cases higher levels of CO_2 and lower levels of O_2 have shown beneficial effects but these levels have also been reported to have detrimental effects. Madrid and Lopez-Lee (1998) stored Grand Naine green bananas in 3% O_2 or air for 15 days at 14°C and 95% r.h. in a flow-through system to simulate sea freight transport. After storage, the fruit was ventilated in air for 2 days at 14°C , exposed to $300 \mu\text{L L}^{-1}$ ethylene for 24 h at 16°C and then stored at 16°C after treatment with ethylene. They found that the CA stored fruit were firmer and had lower total soluble solids for the first 3 days after ethylene treatment, but these differences disappeared as fruit reached commercial ripeness. They found no significant differences in colour. Agoreyo *et al.* (2007) found that ethylene production in CA conditions was not detected and CA storage increased the postharvest life when compared to fruit stored in air. Several climacteric fruit that had been treated with 60% CO_2 + 20% O_2 + 20% N_2 for 24 h had decreased respiration rate and ethylene production for peaches and tomatoes but that of bananas increased (Kubo *et al.* not dated). Recommended conditions for controlled atmosphere storage of bananas include

- 15°C in 2% O_2 + 8% CO_2 (Smock *et al.* 1967);
- 5% CO_2 or lower + 2% O_2 (Woodruff 1969);
- 20°C 3% O_2 + 5% CO_2 or Williams (*Musa* AAA) in Australia (McGlasson and Wills 1972);
- 15°C in 5–8% CO_2 + 3% O_2 for Bungulan (*Musa* AAA) in the Philippines (Pantastico 1975);
- 20°C in 1.5–2.5% O_2 + about 7–10% CO_2 (Anonymous 1978);
- 20°C in 1.5–2.5% O_2 + 7–10% CO_2 for Williams (*Musa* AAA) in Australia (Sandy Trout Food Preservation Laboratory 1978);
- Maximum of 5% CO_2 (Fellows 1988);

- 5% CO₂ + 4% O₂ (Hardenburg *et al.* 1990);
- 15 °C in O₂ as low as 2% if the CO₂ level is around 8% for Lakatan (*Musa* AA) in SE Asia (Abdullah and Pantastico 1990);
- 2–5% CO₂ + 2–5% O₂ (SeaLand 1991);
- 12–16 °C in 2–5% CO₂ + 2–5% O₂ (Kader 1993);
- 12–16 °C in 2–5% CO₂ + 2–5% O₂ (Bishop 1996);
- 11.5 °C in 7% CO₂ + 2% O₂ in South Africa (Van der Merwe 1996);
- 14–16 °C and 95% r.h. in 2–5% CO₂ + 2–5% O₂ (Lawton 1996);
- 14 °C in 4 or 6% O₂ + 4 or 6% CO₂ for Robusta (*Musa* AAA) (Ahmed *et al.* 2001);
- 12 °C in 3% O₂ + 9% CO₂ or 5% O₂ + 5% CO₂ for Prata (*Musa* AAB) (Botrel *et al.* 2004);
- 12.5 ± 0.5 °C and 97–99% r.h. in 2% O₂ + 4% CO₂ or 3% O₂ + 7% CO₂ for Prata Ana (*Musa* AAB) (Santos *et al.* 2006).

Several climacteric fruit that had been treated with 60% CO₂ + 20% O₂ + 20% N₂ for 24 h had decreased respiration rate and ethylene production for peaches and tomatoes but that of bananas increased (Kubo *et al.* n.d.). Boonyaritthongchai *et al.* (2010) reported that the cultivar Kluai Kai (*Musa* AA) had a short storage life after harvesting. Bananas were exposed at 5% O₂, 10% O₂, 5% CO₂ and 10% CO₂ storage at 13 °C. Bananas were treated with 5% O₂ and 10% O₂ had storage life for 40 and 35 days, respectively. While those in 5 or 10% CO₂ had storage life for 40 days and non-treated had storage life for 30 days. Storage in 10% CO₂ delayed the rate that the peel turned yellow following by 5% CO₂, 5 and 10% O₂, respectively. Firmness was decreased in response to 10% CO₂ by maintaining firmness than other treatments. Colour L value tends to increase in association with turning yellow of bananas during storage (Boonyaritthongchai *et al.* 2010).

High O₂ levels in storage can affect postharvest of bananas. Maneenuam *et al.* (2007) compared the effect of storage in 90% O₂ with storage in 18% O₂ at 25 °C and 90% r.h. on early peel spotting in Sucrier bananas. The fruit had first ripened to colour index 3–4 and then transferred to the O₂ treatments. Peel spotting was quicker in fruit in 90% O₂. A decrease in dopamine levels correlated with peel spotting, indicating that dopamine might be used as a substrate for the browning reaction. Kamdee *et al.* (2009) studied heat treatment of colour stage

3–4 of the cultivar Sucrier at 42 °C and 78% r.h. for 18 h and found that peel spotting was inhibited, but ripening was not impaired and taste and odour remained acceptable during storage at 25 °C and about 78% r.h. To explain this they concluded that the *in vitro* activity of enzymes involved in the production of substrate phenylalanine ammonia lyase (PAL) and in the initial browning reactions polyphenol oxidase (PPO) was inhibited by the heat treatment.

Pesis *et al.* (2001) stored preclimacteric clusters (*Musa* AAA group cultivar Ziv) in 2% O₂ at 20 °C for up to 3 days, then in air at 12 °C for 21 days. After which they treated with ethylene at 18 °C for 24 h and transferred 20 °C for 4 days. The fruit exposed for 2 days to 2% O₂ had the lowest decay and reduced chilling injury symptoms. Ripening was also retarded without impairing the taste. The level of reducing sugars in the treated fruit was similar to that in the control fruit after ripening and shelf life. Although the fruit that had been treated for 2 days in 2% O₂ had reduced decay, the levels were higher than for fruits with the commercial treatment of dipping the cut crowns in 0.2% thiabendazole.

The level of CO₂ and O₂ in the surrounding environment of climacteric fruit can affect their ripening rate. Controlled atmosphere storage has been shown to suppress the production of ethylene by fruit. The biosynthesis of ethylene in ripening fruit was shown in early work by Gane (1934) to cease in the absence of O₂. Ethylene concentrations in the core of apples were generally progressively lower with reduced O₂ concentrations in the store over the range 0.5–2% O₂ (Stow 1989a). Wang (1990) reviewed the literature on the effects of CO₂ and O₂ on the activity of enzymes associated with fruit ripening and cited many examples of the activity of these enzymes being reduced in controlled atmosphere storage. This is presumably, at least partly, due to many of these enzymes requiring O₂ for their activity.

Quazi and Freebairn (1970) showed that high CO₂ and low O₂ delayed the high production of ethylene associated with the initiation of ripening in bananas, but the application of exogenous ethylene was shown to reverse this effect. Wade (1974) showed that bananas could be ripened in atmospheres of reduced O₂, even as low as 1%, but the peel failed to degreen, which resulted in ripe fruit which were still green. Similar effects were shown at O₂ levels as high

as 15%. Since the degreening process in Cavendish bananas is entirely due to chlorophyll degradation (Seymour *et al.* 1987a), the controlled atmosphere storage treatment was presumably due to suppression of this process. Hesselman and Freebairn (1969) showed that ripening of bananas, which had already been initiated to ripen by ethylene, was slowed in low O₂ atmospheres.

Goodenough and Thomas (1980) and Goodenough and Thomas (1981) also showed suppression of degreening of fruits during ripening, in this case it was with tomatoes ripened in 5% CO₂ combined with 5% O₂. Their work, however, showed that this was due to a combination of suppression of chlorophyll degradation and the suppression of the synthesis of carotenoids, lycopene and xanthophyll. Jeffery *et al.* (1984) also showed that lycopene synthesis was suppressed in tomatoes stored in 6% CO₂ combined with 6% O₂.

Ethylene biosynthesis was studied in Jonathan apple fruits stored at 0°C under controlled atmosphere storage conditions of raised CO₂ concentrations (0–20%) and low (3%) and high (15%) O₂ concentrations. Fruits were removed from storage after 3, 5 and 7 months. Internal ethylene concentration, 1-aminocyclopropane 1-carboxylic acid levels and ethylene-forming enzyme activity were determined in fruits immediately after removal from storage and after holding at 20°C for 1 week. Increasing CO₂ concentration from 0 to 20% at both low and high O₂ concentrations inhibited ethylene production by fruits. 1-aminocyclopropane 1-carboxylic acid levels were similarly reduced by increasing CO₂ concentrations even in low O₂; low O₂ enhanced 1-aminocyclopropane 1-carboxylic acid accumulation but only in the absence of CO₂. Ethylene-forming enzyme activity was stimulated by CO₂ up to 10% but was inhibited by 20% CO₂ at both O₂ concentrations. The inhibition of ethylene production by CO₂ may, therefore, be attributed to its inhibitory effect on 1-aminocyclopropane 1-carboxylic acid synthase activity (Levin *et al.* 1992). In other work, storing preclimacteric fruits of apple cultivars Barnack Beauty and Wagner at 20°C for 5 days in 0% O₂ with 1% CO₂ (99% nitrogen) or in air containing 15% CO₂ inhibited ethylene production and reduced ACC concentration and ACC synthase activity compared with storage in normal atmospheres (Lange *et al.* 1993).

Low O₂ and increased CO₂ concentrations were shown to have an effect on the decrease in ethylene sensitivity of Elstar apple fruits and Scania carnation flowers during controlled atmosphere storage (Woltering *et al.* 1994). Storage of kiwifruit in 2–5% O₂ with 0–4% CO₂ reduced ethylene production and 1-aminocyclopropane 1-carboxylic acid oxidase activity (Wang *et al.* 1994). Ethylene production was lower in Mission figs stored at 15–20% CO₂ concentrations compared to those kept in air (Colelli *et al.* 1991).

Postharvest physiology

New and Marriott (1974) compared the postharvest physiology of tetraploid banana clones with those of the variety Valery. They found that one tetraploid clone developed serious chilling injury during storage at 12°C, whereas that of five other tetraploid clones showed only slight damage. The preclimacteric period for fruit of two tetraploid clones was 30–45% less than for Valery at an equivalent stage of physical development. Pulp firmness of preclimacteric tetraploid fruit was 20–30% less than that of Valery and the differences persisted throughout ripening. The softening in response to applied ethylene was up to 15 h earlier in the tetraploid clones than Valery but respiratory patterns, colour development and starch-to-sugar conversion were similar. Unlike Valery fruit, ripe tetraploid fruit did not develop senescent spotting and shelf life was terminated by rapid deterioration of peel strength to a state of severe finger drop. Temporal and quantitative differences occurred between fruit of tetraploid clones and Valery in production of ethylene and these may relate to the observed differences in control of softening in both pulp and peel.

Respiration rate

Respiration rate is calculated by measuring their uptake of O₂ or the output from the fruit of such gases as CO₂, ethylene or other organic volatile compounds associated with ripening. Bananas are climacteric fruit and, like other climacteric fruit, ripening initiation is through ethylene biosynthesis via ACC (1-aminocyclopropane 1-carboxylic acid) biosynthesis. Mitochondria of climacteric fruit remain tightly coupled throughout ripening (Young and Biale 1967). The initiation of ripening in bananas occurs when a

threshold level of ethylene is reached within the fruit cells. It is marked by a rapid rise in respiration rate to a peak, after which the rate gradually falls as ripening and senescence progress. The respiratory climacteric is characterized by increased O_2 uptake and CO_2 evolution in a ratio of about 4:10 with CO_2 evolution reaching a maximum of some $250 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ (John and Marchal 1995). Wardlaw and Leonard (1940) measured the respiration rate of Gros Michel at $26.7\text{--}29.4^\circ\text{C}$ and 100% r.h. over a 13-day period. They found that the respiration rate during the preclimacteric phase was $50 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ and at the climacteric peak it rose to $250\text{--}285 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$. During the immediate postclimacteric phase it fell to $120\text{--}130 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ and progressively continued to fall to $70\text{--}75 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ during the final phase. Kader (1989) gave the following effects of temperature on respiration rate, presumably on Cavendish:

- 20 mg for mature-green fruit to $80 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for ripening fruit at 13°C ;
- 26 mg for mature-green fruit to $140 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for ripening fruit at 15°C ;
- 32 mg for mature-green fruit to $200 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for ripening fruit at 18°C ;
- 40 mg for mature-green fruit to $280 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for ripening fruit at 20°C .

In storage at $26.7\text{--}29.4^\circ\text{C}$ and 100% r.h. Wardlaw and Leonard (1940) found that the respiration rate of Gros Michel was higher in whole bunches $3035 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ than for individual fingers $45 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$. At $11.6\text{--}12.2^\circ\text{C}$ the respiration rate of whole bunches was $15 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$.

Wardlaw and Leonard (1940) evaluated the effects of humidity on respiration rate by passing air at either 65 or 95% r.h. through enclosed chambers containing individual Gros Michel fingers. The mean temperature was 29.4°C and the actual humidity in the chambers, because of from the fruits' transpiration, was actually 70 and 100% r.h. They found that the respiration rate during the preclimacteric phase was almost identical and the rise to the climacteric peak had curves of essentially the same pitch. The respiration rate curves then show an almost immediate decrease while those at high humidity had an approximately constant postclimacteric level for 3 days.

Controlled atmosphere storage can affect respiration rate. At $11.6\text{--}12.2^\circ\text{C}$ in an atmosphere of

approximately 5% CO_2 and 12% O_2 the respiration rate was $8 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ and in an atmosphere of approximately 10% CO_2 and 5% O_2 it was $8\text{--}10 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ for whole bunches. This compared with a respiration rate of $15 \text{ mg } CO_2 \text{ kg}^{-1} \text{ h}^{-1}$ in air (Wardlaw and Leonard 1940).

During ripening the fruit softens, starch is converted into sugars, the skin colour changes from green to yellow; they lose their astringency and develop their characteristic flavour. The rapid increase in respiration and conversion of starch into sugars during ripening are indicative of simultaneous increases in both glycolytic and gluconeogenic carbon flows. Based on the rate of conversion of total carbohydrates into CO_2 and sugars during banana ripening, Beaudry *et al.* (1989) estimated that flux through the glycolytic pathway increased four- to fivefold and gluconeogenic flux increased 50- to 100-fold. Pathak *et al.* (2003) concluded that 'ethylene induced ripening of banana is characteristically different from that of other climacteric fruits and that ethylene biosynthesis may have more than one mechanisms operating during ripening which are tightly controlled at various levels.'

During ripening of Cavendish bananas, Hubbard *et al.* (1990) showed that sucrose phosphate synthase activity increased dramatically during the first 4 days after initiation of ripening by ethylene treatment. Sucrose accumulation rate was most highly correlated with sucrose phosphate synthase activity assayed and the cumulative amount of CO_2 respired during ripening was positively correlated with sugar accumulation. From this linear regression it was calculated that a constant 0.605 m moles of CO_2 was evolved per mole of sucrose formed throughout ripening. Using this quantity, the percentage of the total respiratory ATP produced which was required for the conversion of starch into sucrose was calculated assuming different models for carbon export from the amyloplast. The results suggest that sucrose biosynthesis during ripening constitutes a significant sink for respiratory ATP. Bhande *et al.* (2008) developed a mathematical approach to predict the respiration rate through a model based on the enzymatic kinetic with Arrhenius type temperature dependence.

Colour

The pigments in the peel of bananas and plantains are chlorophylls and carotenoids. The change in colour

of ripening fruits is associated with the breakdown of chlorophylls with carotenoid levels remaining relatively constant (Seymour 1985). Cavendish banana cultivars can fail to completely degreen when they are ripened at 25 °C and above (Seymour *et al.* 1987a, Semple and Thompson 1988). This can result in bananas that are ripe in every other respect, but still having green peel. The higher the temperature is, the more pronounced will be the effect. With plantains it was shown that complete chlorophyll destruction can occur even at 35 °C (Seymour 1985, Seymour *et al.* 1987a). Studies on the reason for this effect of temperature on degreening of Cavendish bananas have shown that it appears to be related to the thylakoid ultrastructure of the chloroplasts (Seymour 1985, Blackbourn *et al.* 1990).

Colour changes during ripening of bananas have been used as a rough guide to the stage of ripeness. It is commonly used commercially in the form of colour matching charts based on the degree of peel yellowing where colour index 1 is allocated to fruit that are dark green and colour index 6 is for fruit which are fully yellow (Von Loesecke 1950, Lizada *et al.* 1990). Examples of these colour charts are supplied by commercial banana companies and can also be found in Stover and Simmonds (1987), Abdullah and Pantastico (1990) and Thompson (1996). Advanced stages of banana ripeness are characterized by the appearance of brown flecks or spots on the skin. The brown flecks usually appear after colour index 6 but conflicting reports dispute this. For example in *Musa* AAA, Miem (1980) reported colour index 5.5, whereas Ng and Mendoza (1980) reported that they occur at colour index 3.5–4.

Softening

Softening of bananas during ripening appears to be associated with two or three processes (Smith 1989). The first of these is the breakdown of starch to form sugars since starch granules could have a structural function in the cells. The second is the breakdown of the cell walls due to the solubilization of pectic substances and even the breakdown of cellulose. He also found evidence of increased activity of cellulase during banana ripening. The possible third is the movement of water from the peel of the banana to its pulp during ripening. This latter process could affect the turgidity of the skin that would be enhanced by transpirational losses. Fernandez *et al.* (1996)

reported that in plantains the pulp : peel weight ratio increased from 1.23 in green plantains to 1.60 when fully ripe. This change in the moisture status of the fruit also contributes to the ease of which the peel can be detached from the pulp. Agoreyo *et al.* (2007) showed that the cell-wall-degrading enzyme polygalacturonase in plantains was more active in the pulp than in the peel for all the ripening stages, with the activity increasing from the unripe stage through to the over-ripe stage. Yang *et al.* (2008) found that enhanced production of hydroxyl radical and hydrogen peroxide could participate in the formation of oxidative products, which are involved in the initiation of banana fruit softening. During ripening there are major changes in the pectic polymers in the cell walls. Neutral sugars (mainly galactose in most fruit but also some loss of arabinose) which are major components of the cell wall neutral pectin are lost. There are also losses of acidic pectin. The solubility of these polyuronides increases and in several cases they have been shown to be progressively depolymerized (Tucker and Grierson 1987).

Postharvest diseases

Sigatoka leaf spot

Generally if a crop has suffered an infection during development its storage or marketable life may be adversely affected. Bananas may ripen prematurely or abnormally after harvest because of leaf infections by fungi during growth, which cause stress and therefore shorten their storage life. This can be manifest on the crop before harvesting or it may only be observed as a postharvest physiological disorder. Fungicide applications in the field to control Yellow Sigatoka leaf spot (*Mycosphaerella musicola*) were shown to reduce premature ripening (Meredith 1971, Thompson and Burden 1995). Black Sigatoka is also a leaf spot or leaf streak disease caused by infection with *Mycosphaerella fijiensis*, which has become endemic to most banana exporting countries. Sigatoka is a valley located in the island of Viti Levu in Fiji where the disease was first described in the early part of the 19th century where outbreaks of this disease reached epidemic proportions from 1912 to 1923.

M. fijiensis reproduces both sexually and asexually. The conidia are mainly waterborne short distances, while the wind can carry ascospores considerable distances. Over 60 distinct strains, with

different pathogenic potentials, have been isolated. *Micosphaerella* spp. do not infect the fruit but damages or kills leaves. This reduces the photosynthetic area of the plant that can lead to reduction in yield. This leaf damage in turn causes stress to the plants and a reduction in the green life of the harvested fruit and can result in buff-coloured pulp, increased susceptibility to chilling injury and abnormal flavour and aroma (Gane 1952, Snowdon 1990). It has been found that fruit of infected plants behave as though they were physiologically 1–2 weeks older than those of uninfected plants of the same age. In trials reported by Turner (1997), reducing leaf number from 12 to 7 during fruit growth, which can occur with leaf infections, did not affect bunch weight but reduced green life by 6 days. Ramirez *et al.* (2008) also found that in Grand Naine, grown in tropical commercial banana plantations, it was possible to defoliate the plants to seven leaves at flowering without causing a reduction on the green or yellow life and quality of fruit. With fewer leaves there was no further reduction in green life, but bunch weight was reduced by 8%. Ramsey *et al.* (1990) found that plants with less than five viable leaves (that is five leaves not greatly affected by Sigatoka) at harvest produced lighter bunches, due to smaller fingers. All bunches from plants with fewer than four leaves were field ripe, which in Cavendish means that the pulp is ripe but the peel remains green.

Control of *Micosphaerella* is by spraying with chemicals as often as every 7–10 days in the case of *M. fijiensis*. In Guadeloupe this method of chemical control has resulted in the appearance of strains resistant to the active ingredients used for postharvest disease control (de Lapeyre de Bellaire and Chillet 2000). They also reported growing consumer resistance to chemical use.

Anthracnose

Anthracnose (*Colletotrichum musae*) gives latent fruit infections, the symptoms are numerous small dark circular spots, which generally only become clear as the fruit ripens. Often at harvest there are no symptoms of anthracnose. Wardlaw and Leonard (1940) reported that postharvest anthracnose symptoms appeared 1½ days earlier during ripen at 100% r.h. than at 70% r.h. The time between infection and the symptoms of the disease developing can take over 5 months (Simmonds 1941).

In studies in Guadeloupe stressful growing conditions, especially soil flooding, slowed growth of banana fruit but had no direct effect on their susceptibility to *C. musae* or on their green life. However, fruit that had accumulated lower temperature sums were less susceptible to wound anthracnose. They also showed that bananas of the same grade but different physiological ages had markedly different susceptibility to *C. musae* (Chillet *et al.* 2010). In Brazil the effectiveness of 5 ml L⁻¹ Ecolife® and 0.50 g L⁻¹ Acibenzolar-S-metil was demonstrated on postharvest anthracnose control. This work was on Maï, Prata, Pacovan and Figo varieties harvested at an intermediate stage of maturation that had been inoculated with *C. musae* (Furtado *et al.* 2010). Acedo *et al.* (2001) reported that a hot water dip at 47–52 °C for 10–20 min inhibited anthracnose and finger rot (*Botryodiplodia theobromae* and *Fusarium* spp.) in *Musa* AAB Latundan and *Musa* BBB Saba at ambient conditions of 26–32 °C and 68–90% r.h. When fruits were enclosed in plastic bag during dipping, an indirect hot water dip, a water temperature of 47–49 °C gave as effective control as a 50–52 °C direct hot water dip.

Anthracnose was a problem when bananas were shipped as bunches with prolonged shipping times or when ripened at temperatures above 18 °C. It is rarely seen in hands packed in boxes (Thompson and Burden 1995). Another reason for its demise is the extensive fungicidal field sprays to control *Mycosphaerella* spp.

Crown rot

It is a disease of the cut crown of banana hands and clusters that result from infection with a complex of several fungi and sometimes in association with bacteria (Lukezic *et al.* 1967). An excellent review by Lassois *et al.* (2010a, 2010b) reported that the microorganisms most commonly isolated in crown rot were *Musicillium theobromae*, *Colletotrichum musae*, *Ceratocystis paradoxa*, *Lasioidiplodia theobromae*, *Nigrospora sphaerica*, *Cladosporium* sp., *Acremonium* sp., *Penicillium* sp., *Aspergillus* sp., *Fusarium semitectum*, *F. verticillioides*, *F. sporotrichoides*, *F. oxysporum* and *F. solani*. In India, Sangeetha *et al.* (2010) found that among the 108 isolations made from samples of 16 commercial banana cultivars from different regions, 40 isolations yielded *L. theobromae*, 22 isolations yielded

C. musae, 34 isolations yielded both *L. theobromae* and *C. musae*, 6 isolations yielded *L. theobromae* *C. musae* and *Fusarium* spp. and 6 isolations yielded only *Fusarium* spp. Marin *et al.* (1996) reported that in Costa Rica *F. verticillioides* and *F. semitectum* were the most pathogenic species in crown rot. In the Sudan Thompson and Silvis (1974) reported that the most common genera on the surface of fruit taken from a commercial ripening room were *Fusarium* and *Rhizopus*. Knight (1982) reported that *F. oxysporum*, *F. verticillioides* and *F. graminearum* had been isolated frequently from crowns of Windward Island bananas, while *L. theobromae*, *M. theobromae* and *N. sphaerica* had also been isolated but were considered to be relatively non-pathogenic species. According to Griffie (1976) *C. musae*, *L. theobromae*, *C. paradoxa*, *F. semitectum* and *F. graminearum* were the major pathogens involved in crown rot in the Windward Island. Shillingford (1976), Finlay and Brown (1993) and Lassois *et al.* (2008) confirmed the strong pathogenicity of *C. musae*. Lassois *et al.* (2008) reported that *C. musae* was more pathogenic when it was inoculated alone than when it was co-inoculated with other species. In contrast Anthony *et al.* (2004) in Sri Lanka found that *L. theobromae*, *F. verticillioides* and *C. musae* were more highly pathogenic when co-inoculated than when inoculated separately. Sangeetha *et al.* (2010) found that artificial inoculation in the crown of Robusta showed that the combination of *L. theobromae* and *C. musae* and *L. theobromae* *C. musae* and *Fusarium* spp. produced the highest level of rotting on the ripe fruit.

Umaña-Rojas *et al.* (2011) compared the postharvest development of crown rot from three farms with integrated production systems and three organic farms all located in the Caribbean region of Costa Rica. Results showed lower presence of crown rot in the organic system than in the integrated system. The highest incidence of crown rot occurred in periods of high precipitation and high relative humidity. Lassois *et al.* (2010a) shown that fruit susceptibility to crown rot was variable and they suggested that this depended on preharvest factors. The fruit susceptibility was determined by measuring the internal necrotic surface after artificial inoculation of *C. musae*. A linear correlation was found between the hand position on the bunch and the internal necrotic surface. They also found that fruits of bunches with

six hands were significantly less susceptible to crown rot than those from bunches with eight hands.

Lassois *et al.* (2010b) reported that very little information is available on the epidemiology of crown rot. Some fungi, including some *Colletotrichum* spp., are mainly disseminated by rainwater (de Lapeyre de Bellaire *et al.* 2000), whereas others are airborne (Lukezic *et al.* 1967). Badger (1965) showed that the humidity generally has to be over 86% r.h. for germination of conidia of most fungi involved in crown rot. Crown rot has been shown to vary depending on the season, which probably affects both the pathogens' and the plants' susceptibility to infection. In Jamaica, a high disease incidence was found to be correlated with periods during the year when temperatures were highest (Shillingford 1978), whereas in the Windward Islands, incidence was reported to be highest during the rainy season (Krauss and Johanson 2000).

C. musae also infects other injuries on bananas, particularly those on the ridges of angular fruit, causing decay that spreads into the pulp during ripening. *C. musae* can cause latent or quiescent infections of banana fruit. These infections occur at any time during the development of the fruit in the field as spores on the surface form appressoria and usually only develop as the fruit ripens, causing round lesion known as Anthracnose. These quiescent infections could also contribute to the onset of crown rot if the pathogen has an opportunity to colonize the crown region (Griffie and Pinegar 1974). Field infections may also occur with other fungi but most infections probably occur during harvesting and when clusters are trimmed from bunches (Meredith 1971) or in contaminated washing water (Shillingford 1977). After the banana clusters are dipped in the washing water, the spores can penetrate passively a few millimetres into the vascular vessels of the crown. Disease development is then difficult to control with a fungicide spray treatment (Eckert and Ogawa 1985). Greene and Goos (1963) showed that a suspension of *C. musae* spores could penetrate 5–7 mm into the crown tissues within 3 min. This is because as the crown is cut the break in the xylem tissue means that the column of water, which originally was continuous from the roots to the fruit, is broken. If spores happen to land on the cut surface of the water they will be sucked into the xylem tissue.

Fuzzy pedicel

In the United States in 2007 an unknown problem developed where fluffy grey to white mycelial mats covered large portions of the pedicel surface of Grand Naine fruit when they were packed in gas-permeable containers. Fungi from two genera sporulated on examined pedicels mainly of the genus *Sporothrix* on 72% of the affected pedicels and also *Fusarium* on 6%. They called it fuzzy pedicel (Tarnowski *et al.* 2010). They reported that *Sporothrix* spp. and *F. pseudocircinatum* have not been reported previously on bananas. Fuzzy pedicel development was inhibited at 14 °C but developed at 25 °C. Also it appears that benzimidazole fungicides would be ineffective as a postharvest control treatment.

Other fungal diseases

Several other fungi cause postharvest diseases of fruit. Stem-end rot (*Lasioidiplodia theobromae*, *Thielaviopsis paradoxa* and *Ceratocystis paradoxa*) where the invaded tissue becomes brown, soft and water-soaked stalk. Finger or fruit rot (*Botryodiplodia theobromae*) where rotting usually begins at the tip of the finger or where it is damaged and quickly spreads to rot the whole finger. Pitting disease (*Pyricularia grisea* and *Magnaporthe grisea*) produced small reddish sunken spots. It can be a serious field problem in some areas. It can also be serious on fruit after harvest because of the development of latent infections, which are not controlled by postharvest treatments (Meredith 1963). Cigar end rot (*Verticillium dahliae*, *V. theobromae* and *Trachysphaera fructigena*) is where the rotted tip of the finger is dry and appears similar to the ash of a cigar. Most of these diseases are only occasionally serious where infection levels are high and favourable conditions occur. All postharvest disease organisms are widespread in the field, growing and sporulating on decaying banana or plantain flowers, bracts and leaves. The spores are blown by wind or splashed by rain onto the fruit and are also carried on bunches to contaminate the packing station environment, including the washing water.

Disease control methods

Since most postharvest diseases of bananas originate in the field from infected plant trash, plantation hygiene and a regular disease control programme will play a major part in reducing the inoculum

load. Most species involved in the fungal complex are saprophytes that occur on senescent banana organs, especially on decomposing leaves (Meredith 1962). In some postharvest banana systems such as the one used in many plantations in the Windward Islands, rejected fruit are left in the field as a mulch. When questioned, growers did not believe that this practice or mulching with banana leaves and pseudostems had any detrimental effects. It is important to avoid carrying banana trash to the packhouse. Dead flower remains are a prolific source of fungal pathogen spores. On many commercial plantings the flower remains are removed when the plastic covers are placed on the developing bunches in the field. This also helps to keep the bunch covers intact because as the flowers dry out they become hard and can tear the plastic as it rubs against them in the wind. Bananas taken to packhouses on the bunch are liable to suffer more handling damage and are subject to infection of injuries on the body of the fruit and the cut surface of the crown. This makes it necessary to treat the whole hand with fungicide (Thompson and Burden 1995).

Fungicides

In addition to these precautions it has become necessary to use a fungicide treatment on the deheaded bananas before they are packed for export (Burden 1969). The benzimidazole group of fungicides, especially thiabendazole (2-thiazol-4-yl benzimidazole) and benomyl (methyl-1-[butylcarbamoyl] benzimidazol-1-yl carbamate), have been shown to be effective (Griffie and Pinegar 1974). Thiabendazole is available in the form of wettable powders and emulsifiable concentrates and benomyl as a wettable powder. Concentrations used should be in accordance with local official recommendations. Importing countries have statutory regulations concerning the residue levels permitted on fresh produce. *In vitro* resistance of certain crown rot fungi to benzimidazole fungicides has occurred. Some postharvest fungicides have also been used in the field to control Sigatoka and leaf spot diseases and some others that have been used have the same mode of action. *C. musae* strains resistant to thiabendazole have been detected in many banana producing countries. It has been shown in Guadeloupe that thiabendazole-resistant *C. musae* developed after exclusive foliar applications of benomyl between 1972 and 1982 for Sigatoka disease control (de

Lapeyre de Bellaire and Dubois 1997). Currently imazalil (1-[allyloxy-2,4-dichlorophenethyl] imidazole) is commonly used, often alternately with thiabendazole to reduce the development of fungicide resistance in the pathogens. In the Philippines thiophanate methyl was used to control crown rot on export bananas. However, problems may arise from differences in fungicide efficacy associated with the level of susceptibility of the fruit to crown rot or pathogens to the different fungicides. Finally, discharge of fungicidal slurries can also lead to environmental pollution and residues of fungicides may be detected in the marketed bananas. Several years ago legislation existed in the EU, the United States and other countries that sought to restrict all postharvest application of chemicals to fresh fruit and vegetables; however, in practice most bananas for international trade are treated postharvest with either thiabendazole or imazalil.

Until the late 1960s bananas were transported as bunches and the conversion to cutting the individual hands from the bunch and packing them as hands or clusters in boxes was because Burden (1969) reported that thiabendazole was the first effective chemical control of crown rot.

Application methods

Fungicide application is made after the hands of fruit have been washed, but they must first be drained of excess water, especially when dipping in small amounts of fungicide suspension, otherwise the water adhering to the fruit may dilute the fungicide below its effective concentration. The time between crown trimming and fungicide application is critical. Crown rot severity appeared to increase when fungicide application was delayed (Greene and Goos 1963). Since good coverage of the crown is necessary it is usual to stack the washed hands in perforated plastic trays to drain, followed by fungicide application. The fungicide suspension can be applied by different methods according to the scale of operations and resources available. No matter what application method is used it is essential to keep the fungicide agitated to prevent the active material from settling out. Also, if large amounts of fruits are to be treated it will be necessary to replenish the fungicide from time to time to replace that lost by 'drag out'. For small-scale operations the fungicide can be applied by dipping each hand in a bowl of fungicide or spraying

the upturned hands in a tray using a hand-operated knapsack sprayer. Rubber gloves must always be worn to protect the skin from the fungicide.

In large-scale packhouses fungicide is applied mechanically to run-off, by passing the hands in trays under either a spray or a cascade of fungicide. A problem associated with high-pressure spraying of wettable powder suspensions is the tendency for the spray nozzles to block or for their orifices to wear due to abrasion by the wettable powder. These problems are avoided using a simple cascade applicator (Burden and Griffie 1974, Kemp and Matthews 1974). This uses a low-pressure, high-volume pump to deliver a cascade of fungicide (about 50 L min⁻¹) over the hands of bananas as they are carried down a gravity roller conveyor (Figure 28). The excess fungicide is returned to the reservoir and recirculated. Here again the volume and concentration of fungicide must be restored from time to time when large quantities of fruit are treated.

Anthony (1991) reported studies on the possibility of applying fine charged particles of the diluted fungicide to improve its distribution and effectiveness and reduce potential residue levels. The fungicide was applied over a roller conveyor as in the cascade applicator, but using a fine spray of particles with uniform electrical charges, which repel each other. The bananas are earthed so that the particles are attracted to them. The hands are stacked in trays so that the crowns, which are uppermost, receive the greatest amount of spray.

Bunch covers

Bunch covers have been shown to give some protection from fungal contamination, especially curbing the development of pitting disease (*Pyricularia grisea*) and speckling disease (*Deightonella torulosa*). de Lapeyre de Bellaire *et al.* (2000) reported that bunch covers could reduce contamination of banana bunches by *C. musae* by over 80%.

Controlled atmosphere storage

Control of anthracnose and crown rot infections by storage in 15% CO₂ or 1% O₂ resulted in a reduction in growth of the pathogen but not complete inhibition (Al Zaemey *et al.* 1994). Also these levels of CO₂ and O₂ damaged the fruit so controlled atmosphere storage does not appear to be an alternative to fungicides (Thompson 2010).

Plant extracts

Ranasinghe *et al.* (2005) treated Embul bananas (*Musa*, AAB) with emulsions of cinnamon bark or leaf (*Cinnamomum zeylanicum*). This treatment combined with storage in low-density polyethylene (0.075 mm thick) bags was a safe, cost-effective method for extending their storage life for up to 21 days in $14 \pm 1^\circ\text{C}$ and 90% r.h. and 14 days at $28 \pm 2^\circ\text{C}$ without affecting their organoleptic and physicochemical properties. Antagonists can be used to significantly reduce lesions induced by the fungal complex that causes crown rot, but the control efficacy is limited and variable (Lassois *et al.* 2008). The impact of several natural substances or non-synthetic fungicides, such as preparations of calcium, plant extracts or organic acids, on crown rot development has also been evaluated. *Allium sativum* extracts (Krauss and Johanson 2000) and essential oils of *Cinnamomum zeylanicum*, *Syzygium aromaticum* (Ranasinghe *et al.* 2005), *Cymbopogon nardus* and *Ocimum basilicum* have also been found to have fungicidal activity. Win *et al.* (2007) showed that cinnamon extracts reduced crown rot, increased green life and had no negative effects on postharvest banana quality. Treatments with Biocto 6 (seed extract from citrus) (Productos Biogenicos S.A., San Jose, Costa Rica) combined with a wax-based additive (Verdiol, Productos Biogenicos S.A., San Jose, Costa Rica) was found to provide the same level of crown rot control as fungicide treatments of export bananas (Demerutis *et al.* 2008). There have been recent developments in coatings contained within a plastic film strip for the control of crown rot in organic bananas (Figure 76) similar in concept to the Harcloth crown pads that were used in the 1970s but without the fungicide.

Inorganic salts

Alvindia *et al.* (2004) screened the effects, *in vitro*, of some inorganic salts on *Lasiodiplodia theobromae*, *Thielaviopsis paradoxa*, *Colletotrichum musae*, *Fusarium verticillioides* and *F. oxysporum*. Spore germination of all pathogens was completely inhibited by Na_2CO_3 4 g L^{-1} ; NaClO 5 g L^{-1} and sodium bicarbonate, calcium chloride and sodium chloride 6 g L^{-1} each. Dipping banana fruit for 10–15 min in these concentrations reduced the incidence of crown rot (compared with the untreated fruits) 17 days after harvest in fruits treated with NaClO by 67%, sodium



Figure 76 Plastic covering for control of crown rot disease in organic bananas in 2013. See colour plate section.

bicarbonate by 62%, sodium chloride by 38% and calcium chloride by 33%. Na_2CO_3 -treated fruits had the same incidence of crown rot as untreated fruits. A postharvest dip for 10 min in 300-mM sodium bicarbonate reduced the lesion area of anthracnose on artificially inoculated fruit and natural infections of anthracnose, crown rot and blossom end rot (De Costa and Gunawardhana 2012). They reported that dipping bananas in sodium bicarbonate increased pH, TSS and thickness of the peel, which may have had an indirect or cumulative effect on the reduction of postharvest disease development.

Bacteria

Postharvest dips with *Pseudomonas* sp. isolates associated with the skin of bananas significantly reduced crown rot (De Costa and Subasinghe 1998). Jitareerat *et al.* (2010) reported that *Bacillus cereus* A23 isolated from the soil in a shrimp farm produced the highest chitinase activity and could inhibit the spore germination of banana crown rot pathogens; *Colletotrichum musae*, *Lasiodiplodia theobromae* and *Fusarium* sp. They found that the combined treatments of *B. cereus* A23 with 1-MCP (500 ppb) and active packaging gave good control of crown rot. Dipping banana fruit in 300-mM sodium bicarbonate solution for 10 min followed by dipping in a bacterial antagonist *Burkholderia spinosa* suspension in nutrient broth effectively controlled anthracnose, crown

rot and blossom end rot the variety Kolikuttu (De Costa and Gunawardhana 2012).

Coatings

Banana crowns coated with Semperfresh, which is a commercial product of sucrose esters of fatty acids and carboxy methylcellulose, showed delayed development of crown rot caused by infection with *C. musae*. However, when fruits were inoculated with *C. musae* after harvest the results were inconsistent (Thompson *et al.* 1992). In *in vitro* studies there were reductions in the growth of *C. musae* but there was no complete control. The control of crown rot could be enhanced by the inclusion of organic acids to the coating material (Al Zaemey *et al.* 1993). Treating the freshly cut crowns with citric acid is used on many organic bananas to control crown rots (Al Zaemey *et al.* 1993, 1994). Perera and Karunaratne (2001) reported that effective benomyl application to *Musa* AAB Embul could be reduced by half when applied concurrently with pressure infiltration (1.03×10^5 Pa, for 2 min) of both citric acid and acetic acid.

Varietal resistance

Varietal resistance to crown rot is a possibility. Marin *et al.* (1996) found that FHIA-01 and FHIA-02 were partially resistant to crown rot. However, Perez and Hernandez (2002) reported that FHIA-01 and FHIA-02 were more susceptible to crown rot caused by *F. semitectum* and *C. musae* compared with Cavendish varieties. They also found that only FHIA-23 was more resistant to crown rot than Grande Naine. Sangeetha *et al.* (2010) found that Robusta and Dwarf Cavendish, both *Musa* AAA, were both highly susceptible, and the varieties Karpooravalli, Nendran and Virupakshi, which were all *Musa* ABB, were least susceptible to crown rot disease under artificially inoculated conditions.

Tools

Banana trimming knife tips are rounded to avoid banana fruit wounds (Krauss and Johanson 2000). It is also important to cut wide crown sections containing as much crown tissue as possible, a technique that seems to enhance crown resistance to rot and seldom leads to the spread of rot into the fruit pedicels (Muirhead and Jones 2000).

Humidity

Although most pathogens require a high humidity for their *in vitro* development (Badger 1965), bananas are less susceptible to crown rot at high humidity. Maintaining their turgidity can hamper the senescence of banana crown tissues, which is conducive to crown rot development (Muirhead and Jones 2000).

Modified atmosphere packaging

It was shown that crown rot could be partially controlled by packing bananas in modified atmosphere packaging (Bastiaanse *et al.* 2010).

Hot water treatment

De Costa and Erabadupitiya (2005) showed that the optimum hot water treatment for controlling crown rot was 50 °C for 3 min. A 20-min treatment at a temperature under 45 °C was effective for controlling *C. paradoxa*, with the percentage of infected bananas decreasing from 100% to less than 15% (Reyes *et al.* 1998).

Physiological disorders

Chilling injury

Bananas are subject to chilling injury at temperatures well above freezing. Both green and ripe fruit are susceptible to chilling injury, with green fruit being slightly more sensitive than ripe fruit. Chilling injury occurs by exposure to temperatures at or below 12 °C for a few hours to a few days, depending on the variety, maturity, condition of the fruit, temperature and duration of exposure. Green fruit develop a dull, grey skin colour, starch is no longer converted into sugar and they subsequently fail to ripen properly (Wardlaw 1937). In severe cases they eventually become black and decay. A milder form of chilling injury is under peel discoloration or UPD, which can occur after prolonged storage even at 13 °C. This takes the form of browning of the vascular bundles in the peel and can be seen as faint brown lines just below the peel surface. It is more obvious when the fruit are cut longitudinally or the outer most layer of the peel is scraped back (Figure 77). Chilling injury in fruit may not become apparent until 18–24 h after actual damage has occurred (John and Marchal 1995). Chilling injury is also characterized by increasing membrane permeability as shown by increased relative electrolyte leakage from skin tissue (Jiang *et al.* 2004).



Figure 77 Under peel discolouration in a banana. (Photo: A.J. Hilton. Reproduced with permission of Cranfield University.) See colour plate section.

To avoid this problem bananas are shipped at 13–14 °C. Low-temperature injury can occur where fruit are exposed to temperatures below about 10 °C in the field e.g. in the Sudan during winter the night temperature is often low in winter and poor quality deformed bunches can be produced. Trejo-Marquez and Vendrell (2010) reported that banana fruits from Canary Islands were stored at 4 °C for 1, 3 and 5 days and then re-warmed at 20 °C until ripening. Fruit exposed to 4 °C for 1 day and transferred at 20 °C developed slight damage by the end of storage, showing dull yellow colour in the peel. Neither physiological nor quality parameters were affected. Fruit exposed to 4 °C for 3 days had moderate damage by the end of storage and those exposed for 5 days had severe chilling injury symptoms.

When air is passed through UV light some of the oxygen molecules are broken down for an instant to atomic oxygen and ozone. This can have the effect of destroying pathogens when the fruit or vegetable is passed through the light. Pongprasert *et al.* (2011) treated Cavendish fruits with UV-C at dosages of 0.03 kJ m⁻² prior to storage at 8 or 25 °C. The UV-C-treated fruit had reduced incidence and severity of chilling injury at 8 °C. They accounted for this by the UV-C treatment reducing membrane damage. This reduced chilling injury was thought to be related to lower activity of lipoxygenase and malondialdehyde content. In additions, the *in vitro* polyphenol oxidase activity was activated when fruits were stored at 8 °C and UV-C treatment could inhibit the polyphenol oxidase activity.

In other fruit chilling injury has been shown to affect ethylene production. Exposure of kiwifruits to chilling temperatures for at least 12 days stimulated ethylene production when the fruit were removed to ambient temperatures. However, fruits removed

from prolonged storage at 0 °C in conventional or controlled atmosphere storage showed reduced capacity to produce ethylene because of reduced ACC production and ACC synthase and ACC oxidase activities. Ultralow O₂ storage inhibited ethylene production by chilling, mainly by destroying the system that converts ACC into ethylene (Sfakiotakis *et al.* 1999). In mangoes injurious levels of CO₂ irreversibly inhibited the production of ethylene by inhibiting the enzyme ACC oxidase. Lower levels of CO₂ acted at the same sites to reversibly inhibit ethylene production. Less extreme levels of O₂ acted at the same sites to reversibly inhibit ethylene production (Bender *et al.* 2000b).

There may be variation in susceptibility to chilling injury in different banana types. Promyou *et al.* (2008) found that the peel blackening symptom of chilling injury at 4 °C developed more rapidly on Gros Michel (*Musa* AAA called Hom Thong in Thailand) than Namwa (*Musa* ABB). The results suggest that the rapid peel blackening in Gros Michel was related to detectable membrane degradation, whereas the membrane-associated changes might be below the detection limit in the slower blackening cultivar Namwa. They found that hot water treatment at 42 °C for 15 min delayed peel blackening during cold storage by about 4 days in Gros Michel and by 2 days in Namwa. In both cultivars the delay of blackening was correlated with an increase in the ratio of unsaturated to saturated fatty acids.

Promyou and Ketsa (2010) stored the varieties Hom Thong (*Musa* AAA) and Namwa (*Musa* ABB) at 4 and 12 °C and 85–90% r.h. At 4 °C peel blackening was visible after 2 days on Hom Thong and after 4 days on Namwa. Levels of total free phenolics, thiobarbituric acid reactive compounds and *in vitro* peroxidase activity in the peel were not correlated with blackening but there was a rapid increase of *in vitro* lipoxygenase activity in Hom Thong, which was correlated with blackening. The later blackening in Namwa was not accompanied by increased *in vitro* lipoxygenase activity.

Pan *et al.* (2007) reported that treatment with hydrogen peroxide, salicylic acid or methyl jasmonate alleviated the chilling injury symptoms during storage of banana fruits. They also found that all the treatments could retard the change of the fruit colour and increase polyphenol oxidase activity, relative electrical conductivity and respiration rate.

Banana fruit were dipped for 3 min into hot water at 52 °C and then stored at 7 °C for 10 days. Application of hot water reduced the chilling injury of the fruit, suggesting its putative role in increasing chilling resistance. Hot water-treated banana fruit exhibited lower levels of membrane permeability and H₂O₂ content and higher activities of catalase and ascorbate peroxidase in peel tissues. It was also found that hot water induced the activity of calcium-ATPase of banana fruit (Wang *et al.* 2008a). Chlorophyll fluorescence is a useful indicator of several postharvest stresses. Chlorophyll fluorescence has also been used as an indicator of chilling stress in banana (Smillie *et al.* 1987).

Pulpa crema

The pigments in the peel of bananas are chlorophylls and carotenoids. The change in colour of ripening fruits is associated with the breakdown of chlorophylls with carotenoid levels remaining relatively constant (Seymour 1985, Montenegro 1988). The presence of chlorophyll in the skin masks the yellow colour of the carotenoids (Blackbourn *et al.* 1990). Seymour *et al.* (1987a, 1987b) and Semple and Thompson (1988) showed that as the ripening temperature increases over 20 °C progressively less chlorophyll breaks down during the ripening process of Cavendish bananas. This can result in bananas, which are ripe in every other respect, remaining green. The higher the temperature is, the more obvious will be the effect. It is one cause of the physiological disorder of Cavendish bananas often referred to as *pulpa crema* in Latin America and 'yellow pulp' in the Caribbean. This is where banana fruit are initiated to ripen on the plant, but because the ambient temperature is above 25 °C the pulp ripens but the chlorophyll in the skin is not fully broken down. It commonly occurs when the plant is under stress from insufficient water or fungal infections of the leaves particularly leaf spot and Sigatoka (*Mycosphaerella* spp.). It may not be obvious at harvest but shortens the postharvest life of the fruit. In certain parts of Ecuador comparatively high levels were reported (Thompson and Seymour 1984). Wainwright and Hughes (1989) in their studies of *pulpa crema* also indicated that the disorder was associated with the plants being under stress while being grown in adverse conditions. Studies on why this effect of temperature on degreening of Cavendish bananas occurs failed to reach a definitive

conclusion, although there was some indication that it was related to the thylakoid ultrastructure of the chloroplasts (Seymour 1985, Blackbourn *et al.* 1990).

Maturity bronzing

A condition known as maturity bronzing or maturity stain has been observed in Australia and Central America at certain times during the year, 20–30 days before harvest (Stover and Simmonds 1987). The fruit is unacceptable for market, although eating quality was unaffected. This disorder has been associated with water deficits at bunch emergence during rapid fruit growth under very humid and hot conditions (Williams *et al.* 1990). If bananas are exposed to temperatures above 30–35 °C ripening can be irreversibly inhibited. They referred to this as *high-temperature injury*.

Sunscauld

Sunscauld is where fruit have been exposed to direct sunlight, especially where bunches are enclosed in transparent polyethylene film sleeves. Peel cells are killed leaving a brown stain (Figure 2). Damaged fruit can be graded out at harvest so it is not a major problem.

Local transport

In various studies by the author in several developing countries it was found that they had extremely high levels of damage, but since the price was the same whether they were damaged or not very little effort had been used to improve the system. In the Sudan packing the bananas in plastic boxes for transport greatly reduced these losses (Silvis *et al.* 1976). In Ghana plantains are transported to the market in a similar way and the damage does not seem to matter since even fruit that are crushed almost to a pulp still find a ready market at similar prices to fruit with little damage (Ferris *et al.* 1993).

Case studies

Colombia

Ovalle Huertas and Rueda Mantilla (1998) described the system of postharvest handling of bananas for the local market as distinct from the export market that is concentrated near the Caribbean coast in northern Colombia. For the local market Cavendish is grown and also Gros Michel that is still grown commercially

and is locally preferred to Cavendish and achieves a higher price. The production and postharvest systems were similar to those used for export but overhead cableways were not available. Bunch covers were used and ribbon tagging to determine harvest maturity, but the bunches were cut from the plants and by partly severing the pseudostem. While one worker holds the bunch another worker cuts the pseudostem. The bunch is then tied to a pole suspended between two stakes. The bunch is then transported to the packhouse suspended on a pole. The hands are cut off in the packhouse and packed in plastic boxes or cartons for transport to market.

In Colombia plantains were usually cut into fingers and stacked in the back of lorries padded with plantain leaves for transport to the market. This system works well and but often unacceptable quality of fruit was delivered to the markets. Supermarkets subsequently provided plastic boxes to growers in which to pack their fruit directly in the field, which worked well (Thompson 1978a, 1998).

Eritrea

Banana production was first introduced in 1945 in Somalia by an Italian called Jacamo Jubonty. Ninety hectare was then planted in Engerne, Agordet (Aregay, Personal communication). The major banana producing area in Eritrea is the central lowlands. The distance from Agordat to the ripening rooms in Asmara is about 176 km along paved roads. In Agordet there were 230 banana producers, in the Tessenai there were 25 and in Haicota 10 (Ogbalidet Drar and Thompson 2010). The majority of the bananas grown in Eritrea are Dwarf Cavendish (88%) with some Williams and Grand Naine. The banana industry was devastated by the war and exports ceased in the 1970s and has still not recommenced. In 2002 there was 1054 ha under production, which yielded 21,082 tonnes. However, banana production and postharvest methods were reported to be inadequate thus leading to inferior quality fruits, with poor visual characteristics when ripe and all marketed locally (Ogbalidet Drar 2006). For local transport banana bunches were packed in lorries padded with banana leaves and transported from the field to the ripening rooms and they are very badly bruised fruit on arrival (Figure 73). In some ripening rooms

kerosene stoves are ignited for a short time after the fruit has been loaded to initiate ripening. The room is then kept closed for 24 h to contain the gases given out by the kerosene. These involved in transport and ripening do not normally take good care of the fruit because, they claim, the price they receive is only related to their weight and not quality.

Sudan

For local transport in the Sudan banana bunches are packed in lorries padded with banana leaves and transported from the field to the ripening rooms. In the Sudan, Silvis *et al.* (1976) showed that transporting bananas bunches stacked in the back of a lorry padded with banana leaves and pseudostems from the field could result in considerable damage to the fruit. The mean weight losses varied between 10 and 23% between harvest in Wad Ramli (70 km north of Khartoum), transport to Khartoum and ripening in local commercial ripening rooms in the market (Silvis *et al.* 1976). When the bananas bunches were placed in polyethylene bags for transport or they de-handled in the field and transported in boxes the level of damage was considerably reduced (Table 66) especially if the boxes were lined with polyethylene film.

Uganda

Uganda has the highest per capita consumption of bananas and plantain of 243 kg per year compared with 7–15 kg per year in Europe (Robinson and Saúco 2010). Several banana varieties are grown in Uganda but the commercially important ones are Matoke (Figure 78), Dwarf Cavendish and Apple. Some evaluations of genetically modified bananas were being undertaken near Kampala. Matoke is a major staple and is prepared from green fruit that are peeled, wrapped in leaves, steamed and mashed into a paste. For the local market harvest maturity is judged on the size and shape of individual fingers.

Table 66 Percentage of fruit with neck damage that occurred during transport from Wad Ramli to Khartoum in the Sudan (figures are the mean of nine experiments)

	Bunches (%)	Hands in boxes (%)
Polyethylene bags	8	4
No polyethylene bags	16	4



Figure 78 Matoke bananas being transported to market in Uganda in July 2009. Note that they are packed in split banana pseudostem to protect them during transport. See colour plate section.

When the farmer considers the fingers are sufficiently rounded the whole bunch is harvested. They may be taken to the market on a bicycle. For the main centres of population the bunches are loaded on to lorries padded with leaves and pseudostems and taken to central wholesale markets. Apple and Dwarf Cavendish are commonly ripened there and supplied to retailers. There they may be sold onto retailers or cut into hands for sale.

International transport

Fresh fruit and vegetables are largely transported in temperature-controlled cargo space in either 'break bulk' or containers such as 'reefers', porthole or ventilated types. International sea transport of perishable foodstuffs, using refrigeration, began in the latter part of the 19th century. The BBC website (<http://www.bbc.co.uk/news/business-19462584>) reported in September 2012 that Fyffes group reported revenues up 20% to € 550m and posted a pretax profit of € 22.4m in the first 6 months of

the year, up nearly 30% from 2011. However, Fyffes warned of higher banana prices because of adverse exchange rates and rising fuel costs of some 20%.

Sea freight

Origins

Davies (1990) quoted a statement attributed to an American shipping reporter called William H Bennett that 'an unnamed merchantman first brought Caribbean grown bananas to our shores in 1690. The shipment probably came from Panama'. Davies goes on to comment on the likelihood of odd lots of bananas being brought to American ports since many ships were involved in trade in that area. A report of such trade has not been preserved but 'a semi-authenticated account' reported that the schooner Reynard transported 30 stems from Cuba to New York in 1804. However, no regular trade occurred although in 1843 three hundred stems of 'Cuban Reds' were auctioned in New York. By 1850 Davies (1990) reported that larger clipper schooners started to deliver substantial quantities of red and yellow bananas from Cuba. Probably the first commercial export shipment of bananas from Jamaica to Boston was 500 stems in 1866. It took 14 days and the fruit were said to have been sold at a profit (Sealy *et al.* 1984). There was no indication of temperature control during this or subsequent shipments in the latter part of the 19th century. In 1864 a ship propelled by steam was first used to transport bananas (Davies 1990). Six dozen bunches of green bananas were shipped from Panama and, after an 11-day voyage, were sold in New York at 100% net profit.

In 1866 Captain George Busch loaded 500 stems into a small wooden ship in Oracabessa and Port Antonio. These were unloaded in Boston 14 days later and sold at a profit. This was so successful that Busch returned to Jamaica to encourage small farmer planting of bananas and in 1869 he sent seven cargoes of bananas and coconuts to the United States. The trade apparently became regular and in the summer of 1870 over 3000 stems was transported in three steam ships from Panama. Also in 1870 Captain Lorenzo Dow Baker transported some miners from the United States to Venezuela and on the return journey his ship, the *Telegraph*, called at Port Antonio for repairs.

He secured a cargo of 160 stems of green bananas and on return to New Jersey, which took 11 days, the fruit were sold at a profit. Baker returned in 1871 and transported some 1000 stems to Boston taking 18 days because of bad weather. The fruit, however, were still in excellent condition and achieved a high return (Davies 1990). Unfortunately, not all subsequent shipments arrived in good condition because of comparatively shipping times in sailing ships. In 1879 steam ships as well as schooners were being used to transport bananas from the Caribbean Islands and Central America to the United States. The fruit were shipped with no control of the holds and in 1901 the vessel Port Morant carried 23,000 stems of bananas from Jamaica to Britain using mechanical refrigerated holds for the company Elder and Fyffes (Sinclair 1988).

There are many accounts of the escapades of the US banana companies in Central America. One non-US company manager claimed that his staff was attacked and boxes of fruit were thrown overboard by a US company in Honduras. Smith (2006) reported that in the early years of Central American banana trade the head of United Fruit married the daughter of the Costa Rican President. United Fruit subsequently started to acquire the other fruit companies in Costa Rica. He also reported that in the 1950s United Fruit convinced the CIA that the elected government of Guatemala threatened United Fruits. The CIA placed a right-wing dictator loyal to United Fruit in power securing United Fruit's position in Guatemala.

Gros Michel was shipped at 11.7–12.2 °C and Lacatan at not less than 14.4 °C. They were harvested at the heavy full $\frac{3}{4}$ stage for the 7-day journey to the US market at full $\frac{3}{4}$ stage for the UK market since the journey was longer. The mean finger weights were 145 g for heavy full $\frac{3}{4}$ stage and 117 g for full $\frac{3}{4}$ stage that was reached in 80–90 days (Gane 1952).

Gros Michel was the fruit that dominated the international trade from its beginnings in the mid 19th century until the 1940s. It is a tall heavy bearing variety but is susceptible to Panama disease (*Fusarium* root rot) caused by the fungus *Fusarium oxysporum* f. sp. *cubense*. It was reported as early as 1928 in Trinidad that there was concern about the susceptibility of Gros Michel to Panama disease (Wardlaw 1937). Cavendish was resistant to Panama disease and replaced Gros Michel. The change over started in the 1940s. For example Jamaica exported 49,681 tonnes

to the United Kingdom in 1946, all of which were Gros Michel. Plantations began to be replanted and in 1947 61,766 tonnes of Gros Michel was exported and 29 tonnes of Lacatan. In 1949 69,675 tonnes of Gros Michel was exported and 1584 tonnes of Lacatan (Gane 1952).

Reefer ships

Break bulk refers to a system of transport where individual boxes or pallets of produce are stacked directly in the hold of the ship. It is used to transport almost all bananas that enter international trade. Bananas account for some 35% of the fresh produce transported in this way. Most produce is palletized before shipping and maintained in this condition throughout the marketing chain; in some cases this is right up to the retail outlet. Palletization reduces handling and therefore labour costs and damage to produce. The standard international pallet is 1000 × 1200 mm on which produce is commonly stacked to some 2100 mm high. The holds of ships are commonly 2200 mm high and reefers the same or higher so that pallet loads can fit in with an adequate clearance to allow for air circulation. Boxes should be secured on the pallet with edging strips so that they do not move during transport. During season when the seas are rough there is a considerable increase in the level of damage to boxes and to the fruit they contain. Dunnage or inflatable bags may be placed between pallets to improve air circulation and temperature control (Thompson 2003).

Refrigerated containers

Reefers are insulated containers that have their own individual refrigeration units. They are built to International Standards Organisation specification. ISO specifies that they must be sufficiently strong so that they are capable of holding 30 tonnes and withstand a vertical load of up to nine containers stacked above it. These containers have about 70 mm of insulation in the walls, generally polyurathane foam. A new insulated container will have a heat leakage of about 22 W K⁻¹ but some containers designed solely for the carriage of fresh fruit will have thinner insulation with a heat leakage of around 35 W K⁻¹. The foam almost always contains low conductivity halocarbons to improve performance. Insulation efficiency reduces with time, because of the loss of halocarbons and moisture ingress, by about 3–5% per year (Heap

1989). Reefer containers can have a diesel generator fitted or attached to them so that its contents may be cooled directly after it has been loaded and on the journey to the port.

Refrigerated containers were first introduced in the 1930s but it was only in the 1950s that large numbers were transported on ships, which began between the west coast of the United States and Hawai'i. In the late 1960s the porthole container was introduced. Different operators developed different specifications and sizes of the various types of container. This was particularly evident in their length that varied from 17, 20, 24, 35 and 40 feet long. This variation prevented interchange of containers between different operating lines. Currently only a small part of the world supply of containers deviate from the standard 20 and 40 foot lengths recommended by the International Standards Organisation in 1967. The first purpose built container ship was completed in 1969 which had a capacity of 1300 twenty-foot equivalent units and during succeeding years they have increased in capacity. Numbers have also increased, for example over the period 1970–1988 the world container fleet increased from 195,000 twenty-foot equivalent units to 2,869,000 twenty-foot equivalent units. For bananas refrigerated containers are more expensive than break bulk and can only be used economically where the trade is subsidised, as in Martinique and Guadeloupe through the EU Common Agricultural Policy, or where a higher price is obtained for the fruit as in Ghana through the Fair Trade Organization (Thompson 2003).

Controlled atmosphere containers

The systems used to generate the atmosphere in the containers falls into three categories (Garrett 1992).

The gases that are required to control the atmosphere are carried with the container in either a liquid or solid form. This involves injecting nitrogen into the container to reduce the level of O_2 with often some enhancement of CO_2 . If the respiration of the crop was high the O_2 could be replenished by ventilation.

Membrane technology is used to generate the gases by separation. The CO_2 is generated by the respiration of the fruit and nitrogen is injected to reduce the O_2 level. Passing the air through fine porous tubes made from polysulphones or polyamides at a pressure of about 5–6 bar produces the nitrogen.

The gases are generated in the container and recycled with pressure and swing absorption technology. Ventilation is used to control O_2 levels and a patented molecular sieve to control CO_2 . The molecular sieve will also absorb ethylene and has two distinct circuits that are switched at predetermined intervals so that while one circuit is absorbing, the other is being regenerated.

Porthole containers

Porthole containers are insulated containers that do not have their own refrigeration unit. Instead they have two 10 cm diameters ports which can be connected to an external refrigeration system via a flexible hose. They are used in ships where the containers are plugged into the ship's refrigeration system. They may also be plugged into a unit at the port to cool the produce while awaiting transport. The advantages of this type of system are that the rental costs on the containers are lower and the units can be cooled more quickly because of the larger refrigeration capacity from the ship's system. Disadvantages are that special facilities are required both at the port and on the ship. Refrigeration can only be started when the container has reached the port and not at the packhouse where it may be loaded. They are not commonly used for bananas (Thompson 2003).

Air Freight

The cartons are packed into closed containers, igloos or net covered pallets which are specially designed to fit into a specific type of aircraft. The pallets or containers are loaded with the fruit and then taken to the aircraft for loading to speed the process. Containers come in various shapes and sizes that are designed to maximize the use of the interior of the aircraft. Air cargo is charged by weight. However, if the volume is greater than 6 L kg^{-1} a formula may be applied by the airline to increase the basic charge.

Case studies

Thailand

Gros Michel is grown in Thailand for export to Japan. Harvest maturity is judged on the colour change of the pulp. When it turns a pale yellow colour the bunch is harvested. In fact this method actually means that ripening has been initiated on the plant. Bunches are carefully cut from the plant and suspended from a

pole, with one bunch at each end and carried on the shoulder of the worker. They are loaded into the pickup with foam sheets placed between each bunch to protect them during transport. On arrival at the packhouse bunches are hung from rails and deheaded then washed and placed on a padded bench covered with polyethylene film for grading. As they are loaded into the export cartons, sheets of plastic foam are placed between the fingers to protect them. They are packed into a polyethylene bag inside a telescopic boxes with foam is packed between each layer of fruit. The polyethylene liners are pulled up and over to close and it is tied down. Cartons are then transported by road to the airport for transit to Japan.

Uganda

Some very small quantities of Matoke are air freighted from Uganda to the United Kingdom for the ethnic market. Harvest maturity is judged on the shape and size of the fingers. The bunches are cut from the plant and carried in the arms or on the shoulder or head of the workers to a cleared area at the side of the field. A plastic sheet is placed on the ground and cartons are brought in a lorry and assembled on the sheet. The boxes used were two-piece half-telescopic cartons. The bananas are cut into clusters and packed into the boxes to 10 kg net weight. Lids are placed on the boxes, they are tied with string and loaded onto the lorry. They are driven directly to the airport where they are loaded. Harvesting and transport are co-ordinated with the flights so the fruit are at the airport for a short time and they are flown out on the day of harvest.

Ripening technology

Room design

The design of ripening rooms is very important. Primary requirements are that they should have a good temperature control system, good and effective air circulation, and that they are gas tight and have a good system for introducing fresh air.

Humidity

High humidity of 90–95% r.h. in the rooms, especially in the early stages of ripening, results in better quality ripe fruit. To this end many rooms are fitted with some humidification device such as a spinning disc humidifier. However, if the rooms are full

of bananas and the refrigerant in the cooling coils used to maintain the room temperature is regulated to within a few degrees of the room temperature then this should be sufficient to keep the humidity high.

Conventional rooms

Air circulation around the fruit is important to prevent local accumulations of the CO₂ given out by the fruit and to ensure good contact between the fruit and the ethylene gas applied to initiate ripening. Export boxes of bananas are lined with polyethylene film and usually transported to ripening rooms stacked on pallets. In order to initiate them to ripen it is common practice to remove each box from the pallet, pull back the plastic film and re-stack them on pallets so that there is a space between boxes. This is especially important where fruit have been vacuum packed. Air circulation systems are usually largely based on convection. Air is blown through the cooler and then across the top of the store just below the ceiling. The cooled air falls by convection through the boxes of fruit and is taken up at floor level for recirculation.

Pressure rooms

During the 1990s there was an increasing demand for all the fruit being offered for sale in a supermarket to be of exactly the same stage of ripeness so that it has an acceptable and predictable shelf life. This led to the development of a system called pressure ripening (Figure 67). The system was the same as that for conventional rooms, and it also involves direction of the circulating air so that it was channelled through the pallets of boxes and to give better air circulation. Special devices such as inflatable air bags placed between pallets are now used to ensure better air circulation and, therefore, more even fruit ripening. This results in the ethylene being in contact equally with all the fruit in the room. At the same time the CO₂ was not allowed to concentrate around the fruit. Pallets of cartons, which were originally packed at the producing country, can be stacked directly in the room. This saves the labour of unpacking and restacking used in conventional rooms. The pallet loads can also be removed from the rooms when the fruit is ripe for distribution to the retailer.

Ventilation

Good ventilation to enable fresh air to be introduced is very important for successful banana ripening.

During the period of initiation of ripening, which is usually the first 24 h, no fresh air is introduced to the rooms. This is the period when ethylene is introduced to the rooms. Directly after this period the rooms must be thoroughly ventilated. In a study in Ecuador (Thompson and Seymour 1984) it was found that the CO₂ level of ripening rooms had gone up to 7% during this 24-h initiation period. Even with a good fan extraction system it took 40 min of ventilation to bring the CO₂ levels to below 1%. This ventilation with fresh air must be repeated every 24 h during subsequent ripening. If rooms are not frequently ventilated ripening can be delayed or abnormal ripening can occur.

Gas tight

The rooms need to be gas tight in order to ensure that threshold levels of ethylene are maintained around the fruit during the initiation period. The most common place where leakage occurs is around the doors. It is, therefore, crucial that special gas-tight doors are fitted and that they have suitable rubber gaskets. These must be inspected regularly to ensure that they have not been damaged. Gas can also be lost through the walls of ripening rooms. Commonly these are metal lined on the inside with mastic or gas-tight paint between joints to ensure no gas can pass through them. Gas-tight paint can also be used on walls. All holes through the walls for plumbing and electrical fittings must be blocked with mastic or a gas-tight sealant. All electric fittings and thermostats must be of a special 'spark free' type.

Ethylene application

Methods

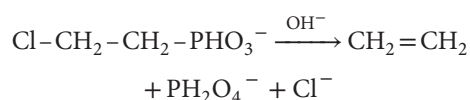
With bananas very low concentrations of ethylene are sufficient for mature fruit at 14–19 °C (the temperatures commonly used commercially). These are in the range 1–10 ppm (µl L⁻¹) for 24 h. However, in commercial practice 1000 µl L⁻¹ is commonly used to ensure ripening. This was partly because many ripening rooms are not fully gas tight and the concentration may be rapidly reduced through leakage. Giant Cavendish bananas from various commercial sources in the Caribbean and Latin America were all successfully initiated to ripen by exposure to 10 µl L⁻¹ ethylene for 24 h at 19 °C (Thompson and Seymour 1982). The same paper records that 1000 µl L⁻¹ acetylene for

24 h at 19 °C was required to achieve the same ripening initiation. This requirement of higher concentrations of acetylene than ethylene to achieve a similar biological effect had previously been described by Burg and Burg (1967).

There are several sources of ethylene that can be used in fruit ripening and degreening. The source and the method selected for applying ethylene to fruit depend on cost, convenience and safety factors.

Liquid

Compounds that decompose in or on the crop to release ethylene can have the advantage of easy application. Etacelasil (2-chloroethyl-tris-[ethoxymethoxy] silane) or ACC (1-aminocyclopropane-1-carboxylic acid), which is the immediate precursor of ethylene biosynthesis in plants, has not been used practically for the application of ethylene to crops. However, 2-chloroethyl phosphonic acid, which is commonly called Ethrel or Ethepon, has been used as a source of ethylene for decades and a voluminous literature exists on its application and effects. These include initiation of flowering in pineapples, anti-lodging agent in cereals, stimulation of latex flow in rubber, enhanced degreening of citrus fruits and initiation of ripening in climacteric fruit. Ethrel is hydrolysed in plant tissue to produce ethylene, phosphate and chloride.



Ethylene can also be released from Ethrel by mixing it with a base such as sodium hydroxide. Ethrel 'C' will release 93 g from 1 to 74.4 L of ethylene gas per litre of Ethrel. It has been used in this way to initiate fruit to ripen by placing containers of Ethrel in a gas-tight room containing the fruit and then adding the base to the containers. It is a simple effective method of initiating fruit ripening but tends to be expensive compared to other methods. Degreening of citrus fruits can be achieved by dipping fruit in 1000 µl L⁻¹ Ethrel, which had the same effect as exposing them to 50 µl L⁻¹ ethylene gas for 24 h (Amchem information sheet 46). Direct dipping of crops in Ethrel, which are to be eaten, may be governed by food legislation in some countries.

In commercial ripening rooms in the Yemen buckets of sodium hydroxide were placed throughout the ripening rooms. When all these were in place measured amounts of Ethrel are added. This gave an instant release of ethylene gas into the room. This is a simple effective method but tends to be very expensive. A comparison was made between using this method and initiating ripening with calcium carbide. The Ethrel method was found to be some 50 times more expensive (Thompson 1985).

Large gas cylinders

Ethylene is available in large steel cylinders where it is stored under pressure. Typical cylinders are number 1, which is 1520 mm high and 230 mm in diameter, and number 3, which is 940 mm high and 140 mm in diameter. The former contains 15 kg (12.9 m^3) of ethylene and the latter 3 kg (2.6 m^3). Because ethylene is highly inflammable the use of large cylinders of the pure gas is discouraged. In order to allow some margin for error it was usually used diluted with nitrogen. Typical mixtures are 95% nitrogen and 5% ethylene or 95.5% nitrogen and 4.5% ethylene. The method of application was to meter the gas into the ripening room containing the fruit through a pipe. The volume of the room should have been previously calculated and the volume of ethylene introduced calculated with a flow meter and a stopwatch.

Small gas cylinders

These are steel cylinders (also called lecture tubes) which commonly contain 35 L of ethylene (Figure 79). Two types are available. One type has a cover which when it is punctured releases all the gas inside. The second type can be fitted with a metering device to allow for slow and controlled release of the gas. The former was the type commonly used for initiating fruit to ripen commercially. The way it is applied was to calculate the volume of the ripening room and the release the gas from the correct number of cylinders to achieve the correct concentration of ethylene required for ripening or degreening.

Ethylene generators

These are devices that are placed in ripening rooms. A liquid is poured into them and they are connected to an electrical power source and they produce ethylene over a protracted period (Figure 80). The manufacturers of these generators do not provide information



Figure 79 Small ethylene cylinders called lecture tubes.

on exactly what the liquid is which they supply for use in the generators or the process by which the ethylene is generated. A possible way of generating ethylene would be to heat ethanol in a controlled way in the presence of a copper catalyst. Care should be exercised in doing this because of the inflammability of the alcohol.

The way that generators are used is to calculate the volume of the store and place the correct number of generators in the store to provide the required ethylene concentration. This method has the advantage of supplying ethylene to the store over 16 h rather than applying it in one dose from cylinders. This means that there is a better chance of achieving the desired ripening or degreening effect where there are problems of the room being perfectly gas tight. Gull (1981) used this method for ripening tomatoes. Blankenship and Sisler (1991) reported that effluent produced by the catalytic generators had a distinctly different odour than that produced by ethylene from cylinders. When they compared the two methods for ripening tomatoes they found inconclusive results in that taste panellists could detect a difference between the fruit ripened by the two methods, but they did not express



Figure 80 Catalytic ethylene generator.

a preference for either treatment. There tended to be less variation in colour between fruits ripened with ethylene from cylinders compared to those ripened from ethylene generators.

Ripening conditions

Wills *et al.* (1989) gave the recommended ripening temperatures for bananas as a pulp temperature of 18–21 °C using ethylene at 10 μL^{-1} for 24 h in 85–90% r.h. These were also summarized in an international standard (ISO 1977). In a comparison between bananas allowed to ripen naturally with those ripened by exposure to ethylene, the former were considered more fruity, less green and softer in a descriptive panel assessment (Scriven *et al.* 1989). Ripening involves a number of physical and chemical changes that occur in fruit. These normally occur when the fruit has developed to what is referred to as *full maturity*. However, immature fruit may be harvested and exposed to certain postharvest conditions particularly temperature, humidity and gas content in the atmosphere, which are conducive to ripening. The changes can occur during ripening, which may

be independent of each other, but under the correct circumstances these processes are initiated together and proceed together producing an acceptably ripe fruit. In other circumstances changes such as reduction in acidity or change in colour may occur at a different rate to other processes producing a fruit which is fully ripe in all other aspects except that one. Initiation of ripening occurs when a threshold level of ethylene is reached in the cells of the fruit. This occurs naturally within the fruit at a point during maturation. It can occur earlier if the fruit undergoes stress for example if a disease-causing microorganism attacks it, or the plant it is growing on. Ripening can also be initiated by exposing the fruit to exogenous ethylene so that the threshold level infiltrates into the cells of the fruit. As fruits approach maturity they become more sensitive to ethylene initiated ripening (Knee *et al.* 1987).

Colour changes during ripening of bananas have been used as a rough guide to the stage of ripeness in many banana cultivars. It is commonly used commercially in the form of colour matching charts based on the degree of peel yellowing where colour index 1 is allocated to fruit which are dark green, and colour index 6 is for fruit which are fully yellow (Von Loesecke 1950, Lizada *et al.* 1990). Examples of these colour charts are supplied by commercial banana companies and can also be found in Stover and Simmonds (1987) and Abdullah and Pantastico (1990). Advanced stages of banana ripeness are characterized by the appearance of brown flecks or spots on the skin. Conflicting reports, however, dispute the colour index at which these superficial spots appear. For triploid bananas of the same cultivar, Miem (1980) reported colour index 5.5, whereas Ng and Mendoza (1980) showed that they occur at colour index 3.5–4.

For Gros Michel, McGuire (1929) stated that they were ripened between 21.1 and 26.7 °C and 90% r.h. 'according to the rapidity with which they are to be ripened to meet the market demand for ripe fruit'. So for Gros Michel it is possible to ripen them at these relatively high temperatures and vary the temperature to control the speed of ripening. In Thailand Gros Michel is allowed to initiate to ripen on the plant. This is assessed by peeling back the skin on a finger and when the pulp has begun to turn a creamy colour the bunch will be harvested.

One main reason for controlled ripening is to provide retailers and wholesalers with fruit at a stage of

ripeness desired by consumers. Generally, very low concentrations of ethylene in the order of 10–50 $\mu\text{L L}^{-1}$ are sufficient to initiate ripening (Thompson and Seymour 1982). In commercial practice however, 1000 $\mu\text{L L}^{-1}$ is commonly used to ensure uniform ripening. This was partly because many ripening rooms are not fully gas tight and the concentration may be rapidly reduced through leakage. Most commercial cultivars of bananas require exposure to ethylene for 24–48 h at 14.4–18 °C (Thompson and Burden 1995, Robinson and Saúco 2010). However, temperatures of up to 20 °C are sometimes necessary (Thompson and Burden 1995). Optimum humidity levels during ripening are 90–95% r.h. After the change in colour from green to yellow is underway the humidity should be reduced to 85% r.h. to prevent peel splitting. However, this is rarely done in practice. High humidity requirements for proper ripening can be achieved when the fruit is being packed in partially sealed polyethylene liners. Exposure of ripe bananas to temperatures higher than those in the ripening range hastens softening and decays, weakens the neck, can cause splitting of the peel and may cause poor colour development.

The colour of the peel is used as an indicator of ripening. A scale of 1–7 is convenient where 1 is dark green, 2 is light green, 3 is more green than yellow, 4 is more yellow than green, 5 is yellow with green tips, 6 is fully yellow and 7 is where brown spots begin to appear. Room ventilation after the application of ethylene is essential to keep CO_2 level low. Thompson (unpublished results) found that in a ripening room in Ecuador the CO_2 level reached 7% within the first 24 h while the room was closed after the injection of ethylene. The use of a pressurized system provides more uniform temperature control and uniform ethylene concentrations throughout the room. When ripening is done in non-pressurized rooms, open stacking of boxes is essential to allow adequate air circulation for uniform ripening. Many stacking patterns are used, the best pattern to be used depends on pallet sizes and ripening facilities. Because heat rises, the amount of box top area exposed is most important for preventing heat build-up in the stack and controlling pulp temperature during ripening. Bananas are usually ripened to colour stage 3–4 before delivery to distribution centres, wholesalers and retailers.

Within certain limits, the period required for ripening bananas can be shortened or extended to meet

trade requirements by adjusting the temperature. Under average conditions, depending on initial temperatures chosen and condition of the fruit, the ripening cycle can be as short as 4 days (>18 °C) or may be extended to 8–10 days (at 14 °C). If initial ripening temperatures are too high (>25 °C), the pulp will soften but the peel will remain green (a condition described as ‘cooked’ or ‘boiled’ fruit) (Turner 1997, Robinson and Saúco 2010). Low temperatures and insufficient ethylene can cause uneven ripening. Ripening rates and characteristics of the fruit vary to some extent between lots depending on cultivar, country of origin, weather conditions during the growing of the fruit, temperatures during handling and transit and maturity of the fruit. Hard-green fruit (less full) will take longer to ripen than more advanced and full fruit.

In Cameroon the changes in the fruits of five cooking banana cultivars and nine desert cultivars were measured by Ngho *et al.* (2009). They found that during ripening, the peel dry matter content increased from 8.63 to 24.20 g 100 g⁻¹, pulp to peel ratio increased from 1.38 to 7.77 g 100 g⁻¹, total soluble solid increased from 1.27 to 19.3 g L⁻¹ and total TA increased from 276.3 to 1491 mEq 100 g⁻¹ of the pulp. Pulp firmness reduced from 3.2 to 0.15 kg cm⁻², pH from 6.34–4.48 and dry matter from 40.12 to 18 g 100 g⁻¹ content of the pulp.

Ethylene

Ethylene is synthesized in plant material. In climacteric fruit copious amounts may be produced especially in bananas. The amount of ethylene synthesized can also depend on harvest maturity, handling method, storage temperature and gaseous content around the fruit. Threshold levels of ethylene will be reached naturally at fruit maturity, but it can also arise by the fruit being put under stress during production by water shortage or infection by disease-causing organisms or by mechanical damage to the fruit during harvesting and handling operations. Exposing fruit postharvest to low humidity may also result in sufficient stress to the fruit to initiate ripening. The threshold level can also be achieved by exposing the fruit, for a sufficient period, to a threshold concentration of ethylene in a gas-tight room if the environmental conditions are conducive. George and Marriott (1982) reported that application of low

concentration of exogenous ethylene ranging from 0.013 to 2.501 ppm considerably reduced the preclimacteric period in plantains. Quazi and Freebairn (1970) showed that high CO₂ and low O₂ delayed the production of ethylene to levels associated with the initiation of ripening in bananas, but the application of exogenous ethylene was shown to reverse this effect. Wade (1974) showed that bananas could be ripened in atmospheres of reduced O₂, even as low as 1%, but the peel failed to degreen, which resulted in ripe fruit which were still green. Similar effects were shown at O₂ levels as high as 15%. Since the degreening process in Cavendish bananas is entirely due to chlorophyll degradation (Seymour *et al.* 1987a), the controlled atmosphere storage treatment was presumably due to suppression of this process. Hesselman and Freebairn (1969) showed that ripening of bananas, which had already been initiated to ripen by ethylene, was slowed in low O₂ atmospheres.

Treatment with 1-methylcyclopropene (1-MCP) can inhibit the action of ethylene. Pinheiro *et al.* (2005), Jansasithorn and Kanlavanarat (2006) and Jiang *et al.* (2004) reported that treatment with 1-MCP increased postharvest life of bananas and Klieber *et al.* (2003) showed that treatment with 1-MCP did not affect eating quality. However, bananas treated with 1-MCP were shown to result in some uneven degreening (de Martino *et al.* 2007).

Bananas are sensitive to physiological levels of ethylene as low as 0.3–0.5 µl L⁻¹ if the O₂ and CO₂ levels are similar to those found in outside fresh air (Peacock 1972). The three main factors affecting response to external ethylene are fruit maturity, time from harvest when ethylene exposure began and the length of exposure to ethylene. The effect of temperature on ethylene production was reported to be

- at 13 °C ethylene production was 0.04–2.0 µl kg⁻¹ h⁻¹;
- at 15 °C ethylene production was 0.15–5.0 µl kg⁻¹ h⁻¹;
- at 18 °C ethylene production was 0.20–8.0 µl kg⁻¹ h⁻¹;
- at 20 °C ethylene production was 0.30–10.0 µl kg⁻¹ h⁻¹.

Ethylene binding by banana fruit stored at 3 and 8 °C decreased with reduced storage temperature and/or prolonged storage time (Jiang *et al.* 2004).

The change in physiology of climacteric fruit from maturation to ripening is initiated when cellular quantities of ethylene reach a threshold level (Yang and Hoffman 1984). The metabolic pathway within the cells of the plant that result in ethylene production is complex. This involves a series of steps culminating in the synthesis of SAM (S-adenosyl-methionine) which is converted to ACC (1-aminocyclopropane-1-carboxylic acid) by the action of ACC synthase. ACC is the immediate precursor of ethylene biosynthesis in plants. ACC oxidase is required to convert ACC to ethylene (Hamilton *et al.* 1990). It is a labile enzyme and is sensitive to oxygen and can be inhibited at temperatures above 35 °C and anaerobic conditions. It was suggested that high levels of CO₂ in stores could compete with ethylene for binding sites in fruits (Burg and Burg 1967). They showed that in the presence of 10% CO₂ the biological activity of 1% ethylene was abolished. Yang (1985) also showed that CO₂ accumulation in the intercellular spaces of fruit acts as an ethylene antagonist.

Little ethylene, or ethylene precursors, has been detected in maturing fruits and it is not clear exactly what causes its rapid production and, thus, the beginning of the climacteric rise. However, the application of ethylene to fruit that are not yet fully mature can initiate the climacteric and the endogenous production of ethylene for example to bananas (Biale 1950). In bananas the principal source of ethylene is its biosynthesis in the fruit pulp (Ke and Tsai 1988). This increase in ethylene synthesis is followed by changes in the fruits' physiology, texture and composition associated with ripening as described above including the typical climacteric rise in respiration.

Threshold levels of ethylene will be reached naturally at fruit maturity, but it can also arise by the fruit being put under stress during production by water shortage or infection by disease-causing organisms or by mechanical damage to the fruit during harvesting and handling operations. Exposing fruit postharvest to low humidity may also result in sufficient stress to the fruit to initiate ripening. This was shown by Thompson *et al.* (1974) for plantains. The threshold level can also be achieved by exposing the fruit, for a sufficient period, to a threshold concentration of ethylene in a gas-tight room. This is the principal used in most commercial fruit ripening rooms.

When using ethylene great care must be exercised and the operator must wear protective clothing, including a protective face mask and leave the area immediately. Hazard warnings should be put up and flames, cigarettes or electrical fittings that could cause a spark must be eliminated from the area. Kluai Teparod (*Musa* ABBB) were harvested at mature green and ripened at 20 °C and 90% r.h. by Joomwong and Joomwong (2008). Sensory evaluation panellists preferred the appearance and colour of fruit at colour stage 3 (more green than yellow), while the most preferred tastes were that of colour stage 4 (yellow with softening pulp).

Acetylene

With bananas very low concentrations of ethylene are sufficient for mature fruit at 14–19 °C (the temperatures commonly used commercially). These are in the range 1–10 ppm ($\mu\text{L L}^{-1}$) for 24 h. However, in commercial practice 1000 $\mu\text{L L}^{-1}$ is commonly used to ensure ripening. This is partly because many ripening rooms are not fully gas tight and the concentration may be rapidly reduced through leakage. Giant Cavendish bananas from various commercial sources in the Caribbean and Latin America were all successfully initiated to ripen by exposure to 10 $\mu\text{L L}^{-1}$ ethylene for 24 h at 19 °C (Thompson and Seymour 1982). The same paper records that 1000 $\mu\text{L L}^{-1}$ acetylene for 24 h at 19 °C was required to achieve the same ripening initiation. This requirement of higher concentrations of acetylene than ethylene to achieve a similar biological effect had previously been described by Burg and Burg (1967).

The most commonly used alternative is acetylene. It is used in less developed countries throughout the world in the form of calcium carbide because it is cheaper than ethylene sources and easier to apply in simple ripening rooms. Calcium carbide is a by-product of the iron and steel industry and the material available contains impurities. Technical grade calcium carbide of regular chip size of 4–7 mm conforming to British standard BS 642 (1965) is the type most commonly used. If it were pure calcium carbide then 1 kg would produce 300 L of acetylene gas. The gas is released when the calcium carbide is exposed to moisture. The reaction can be violent so the way it is commonly applied is to wrap small

amounts (just a few grams) in twists of newspaper and put these among the bananas to be ripened. The high humidity reacts with the calcium carbide giving a slow release of acetylene. Where large quantities of acetylene are required quickly the small amounts of calcium carbide can be dropped carefully into large buckets of water.

Acetylene has been shown to be effective in initiating ripening of bananas. Thompson and Seymour (1982) showed that bananas were initiated to ripen when exposed to 0.1 or 1 ml L^{-1} at 18 °C for 24 h. Smith *et al.* (1986) showed that the effects of acetylene on bananas were proportional to temperature and exposure time (Figures 62 and 81). Exposure of fruit to 1 ml L^{-1} of acetylene for 4 h did not initiate ripening at between 20 and 30 °C but it did initiate ripening at 35 °C. With 8 h exposure fruit were not initiated at 20 °C, were partially initiated at 25 °C and were fully initiated at 30 °C. Acedo and Bautista (1993) showed that in Latundan (*Musa* ABB) and Saba (*Musa* BBB) bananas exposure of 5 g of calcium carbide for 1-day 'effectively enhanced ripening'. Latundan harvested at full maturity required a lower level of calcium carbide and then Saba harvested at the full $\frac{3}{4}$ stage. It is relevant to note comments in Bangladesh. The Financial Express, Dhaka, Bangladesh, Saturday May 16, 2009, had the following: 'The chemical used to ripen bananas is calcium carbide, and is extremely hazardous to the human body because it contains traces of arsenic and phosphorous. Once dissolved in water, the carbide produces acetylene gas. When the carbide is used on very raw fruit, the amount of the chemical needed to ripen the fruit has to be increased. This results in the fruit becoming even more tasteless and toxic.'

Propylene

The number of studies dealing with the effect of 1-MCP on retarding ripening of partially ripe bananas is limited (Joyce *et al.* 1999, Yueming *et al.* 1999) and no studies have been reported about the effect of 1-MCP on specific stages of ripeness of bananas commercially treated with ethylene. Joyce *et al.* (1999) found that banana ripening induced by propylene, an ethylene analogue, can be delayed by exposure to 15 ml L^{-1} of 1-MCP at 20 °C for 12 h. However, the 1-MCP treatment was less effective as

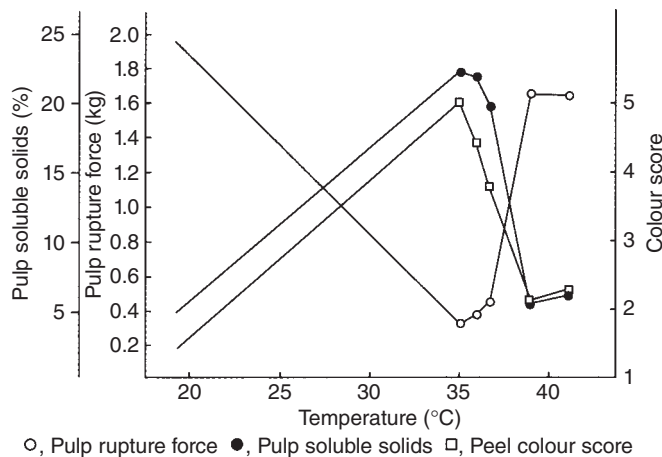


Figure 81 The effects of exposure at 20 °C for 6 days to 1 ml L⁻¹ of acetylene for different times at different temperatures on the ripening of bananas. (Source: Smith *et al.* 1986. Reproduced with permission of John Wiley & Sons Ltd.)

propylene-induced ripening progressed, although it was able to maintain the eating-ripe condition of fruits for a longer time than the control treatment. Similarly, Yueming *et al.* (1999) found that 1-MCP (in a concentration range 0.01–10 ml L⁻¹ at 20 °C for 12 h) applied after 1 day of ethylene treatment slowed the ripening of bananas, but it was ineffective when applied 3 or 5 days after ethylene treatment. In kiwifruits ethylene production was shown to be induced autocatalytically by exposure to exogenous ethylene or propylene, exposure to chilling temperatures, wounding and *Botrytis* infection (Sfakiotakis *et al.* 1999). Concentrations of 10% CO₂ in storage also reduced the rate of propylene-induced ethylene production, while 1–5% O₂ concentrations inhibited propylene-induced ethylene production at the ACC synthesis level (Sfakiotakis *et al.* 1999).

Damage

Wounding the banana bunch stalks or even the fruit may produce ethylene in response to the wound. This has been demonstrated for jackfruit, papaya, chico and avocado in south east Asia (Bautista 1990).

Fruit generation

Fruit that are ripening and thus giving out ethylene can be placed in an airtight room with green fruit. A

continuous system could be worked out for commercial application of this method. However, the room would need to be frequently ventilated to ensure that there was no build up of CO₂, which is known to inhibit the effect of ethylene.

Smoke

Another simple method of initiating ripening is to light a smoky fire in the ripening room. This can produce various gases including acetylene, ethylene and carbon monoxide which will initiate ripening. It is used in many developing countries and a study in the Sudan showed that it appeared to be effective, but there was considerable variation in the speed of ripening throughout the room.

Leaves

A one-day treatment of bananas with *Gliricidia* sp. or rain tree leaves at 5% of fruit weight enhanced ripening of Saba but was less effective than the calcium carbide treatment (Acedo and Bautista 1993).

Banana passionfruit

Passifloraceae

Passiflora mollissima (HBK.) Baily, *P. antioquiensis* Karst., *P. van-volxemii* (Lem.) Triana & Planch,



Figure 82 Banana passionfruit growing close to Bogota in Colombia. See colour plate section.

Table 67 The composition of banana passionfruit fruit from Colombia for 100 g⁻¹ fresh weight (source: Morton 1987)

Calories	25	Ash	0.7 g
Moisture	92.0 g	Calcium	4 mg
Protein	0.6 g	Phosphorus	20 mg
Fat	0.1 g	Iron	0.4 mg
Carbohydrates	6.3 g	Riboflavin	0.03 mg
Fibre	0.3 g	Niacin	2.5 mg
		Ascorbic acid	70 mg

P. tomentosa var. *mollissima* Tr. & Planch and *Tacsonia mollissima* HBK. (Morton 1987). The banana passionfruit is native to the Andean Valleys from Venezuela and eastern Colombia to Bolivia and Peru. It is believed to have been domesticated only shortly before the Spanish Conquest and has been subsequently introduced to New Zealand and Hawai'i. The vine is a vigorous climber up to 6–7 m high; its nearly cylindrical stems are densely coated with yellow hairs. It has large pink flowers and the fruit is oblong or oblong-ovoid up to 12 cm long and 3–4 cm wide (Figure 82). The rind is thick, leathery, whitish-yellow or, in one form, dark-green. The pulp is aromatic salmon-coloured, subacid to acid and rich in flavour. It contains small, black, flat seeds (Morton 1987). The chemical content was given by Morton (1987) in Table 67.

Harvesting

The skin of the fruit changes from green to yellow as they mature and this change can be used to determine when to harvest. Harvesting is by hand.

Postharvest physiology

Tellez *et al.* (1999) found that fruits of two cultivars of *P. mollissima*, Ruizquin 1 and Ruizquin 2, showed climacteric patterns in respiration rates.

Storage

Storage at 10–12 °C and 87–89% r.h. increased their postharvest life by 50% compared to ambient storage at 24–25 °C and 75–77% r.h. Losses of fruit were 2.8% during 30 days storage at 10–12 °C (Collazos *et al.* 1984). Caceres *et al.* (1998) stored green fruit, without disinfecting them, in a cold room with free ventilation at 13 °C and 90% r.h. for 20 days. Storage at 8 °C resulted in a slower loss of weight and firmness, a lower respiration rate, a higher content of TSS, a lower pH value of the juice and a higher percentage of acidity compared with storage at room temperature of about 20 °C (Tellez *et al.* 1999). 'The fruit will keep in good condition in a dry and not too cold atmosphere for a reasonable length of time' (Morton 1987).

Modified atmosphere packaging

Fruit storage in 25 × 75 cm PE film bags of 25, 37.5 or 50 µm thick and with 0, 6 or 12 perforations of 0.5 cm in diameter per bag was investigated. Bags of 50 µm thick with six perforations were found to be the most suitable (Collazos *et al.* 1984).

Diseases

Caceres *et al.* (1998) identified *Colletotrichum* sp. and *Botrytis* sp. on the fruit but the infections caused only minimal or slight damage. Growing plants were sprayed with 0.5 ml L⁻¹ thiabendazole in combination with 3 ml L⁻¹ grapefruit seed extract during the 5 months before harvest with spraying intervals of 7, 14 or 21 days from the appearance of floral buds until the occurrence of green mature fruits. These treatments significantly reduced damage by *Colletotrichum* sp., while *Botrytis* sp. was not detected.

Baobab

Bombaceae

Adansonia digitata L. also called African baobab. Their origin was probably tropical Africa and they



Figure 83 Baobab tree showing new leaves and young developing fruit from the present season with mature fruit from the previous season that had not been harvested. Photograph taken just after the onset of the rainy season in Keren in Eritrea in May 2013. See colour plate section.

have been introduced to Australia, India, Sri Lanka, Indonesia, the Philippines, the Middle East and the West Indies. Their fruit, seeds and leaves are all used for food and the bark is used for its fibres. They have a life span of hundreds of years and are often held in reverence. A tree in Keren in Eritrea is hollow and contains an edifice of a black Madonna, which attracts pilgrims especially on May 29. Baobab is a deciduous, tropical tree up to 25 m high with a massive trunk up to 10 m in diameter supporting a tangled mass of small branches. With the small crown and massive trunk it seems out of proportion and it has been remarked that they look as if they have been planted upside down. The bark is smooth, silver-grey, pinkish-purple or dark grey in colour and contains a yellow or green inner layer, which is composed of thick, tough, longitudinal fibres. It produces fruits that are oblong in shape up to 24 cm long with long stalks (Figure 83). The skin is greenish-grey when young turning brownish as they mature. They have an acid pulp, which contain edible seeds that have 12–15% oil content. SCUC (2006) reported that the fruit has exceptionally high vitamin C content.

Fruits should be harvested only when they are fully ripe. This is judged on the change in skin colour from the green to yellow in immature fruit that turn brown

at maturity. Essentially the fruit should be allowed to dry on the tree. However, skin colour does not change rapidly during maturation. At maturity, the fruits are filled with a white, powdery pulp and the seeds become hard. Fully ripe fruit can be stored unopened for several months. SCUC (2006) reported that whole fruits could be stored on shed roofs or raised platforms with unopened and uncracked fruit for up to 1 year. The fruit pods will dry in the sun and the pulp and seeds will pull away from the inside of the shell.

Bayberry

Myricaceae

Myrica rubra Siebold & Zuccarini synonymous with *M. rubra* var. *acuminata* Nakai and *Morella rubra* Loureiro. Other common names include arbutus, yang mei, waxberry, Chinese bayberry and red bayberry. It is native to Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan and Zhejiang provinces of China and has been naturalized in Taiwan, Japan, Nepal, Korea and the Philippines. It has been grown for at least 2000 years in China. It is native to warm and humid environments. Evidence from a Neolithic site at Homutu in Yuyao (Zhejiang Province) suggests that red bayberry has been utilized for at least 7000 years. Records in Chinese literature suggest that Zhejiang Province has a long history of managing red bayberry plants and the greatest variety of cultivated genotypes (Joyce *et al.* 2005). The evergreen trees can grow up to 10 m or even 20 m high, with smooth grey bark and a round-shaped canopy with dense dark green, glossy, glabrous leaves. They are dioecious and the flowers are borne in panicles. The fruit is a drupe 1.5–2.5 cm in diameter, which has a soft knobby skin that is deep red in colour when fully ripe. It containing mesocarp tissue whose colour is similar to the skin or somewhat lighter and surrounds a seed. The mesocarp is soft and succulent with a pleasant combination of sweet and acid tastes either clinging to or free from the stone. Cultivars have been developed in China for example Donkui that has large fruit weighing 20–25 g (Joyce and Li 2003, Joyce *et al.* 2005).

It is rich in vitamin C, thiamine, riboflavin and carotene and contains calcium, phosphorous, iron and potassium. The fruit are said to have beneficial

health effects, including settling the stomach and bowels and being thirst quenching. Ascorbic acid content increased about 6 days before harvest reduced and then rose again (Li 2001, Wang *et al.* 2002, Joyce *et al.* 2005). Zhang *et al.* (2008) reported that total phenolics, flavonoids, anthocyanins, cyanidin-3-*o*-glucoside and antioxidant capacity differed among the cultivars Baizhong (white), Fenhong (pink), Wuzhong (red) and Biqu (dark red). Greater fruit maturity was associated with higher levels of all the bioactive components and antioxidant capacity. Significant increases were also found during storage of the cultivar Biqu at either 20 °C for 2 days or 0 °C for 5 days. However, these levels decreased during shelf life of 2 days at 20 °C after 5 days at 0 °C. These results show that storage and shelf life conditions are important if bioactive components are to be maintained postharvest.

Harvest maturity

Harvest maturity may be determined on the basis of fruit weight, colour, sugar content, acid level, sugar: acid ratio, flavour and/or days from anthesis. However, in practice, maturity is assessed on the bases of fruit colour and flavour. Total soluble solids increase steadily during fruit colour change up to harvest maturity. TA decreases continuously during maturation and then tended to stabilize (Li *et al.* 2002). Fruits harvested immature tasted sour and failed to ripen fully but fruits that were allowed to ripen on the tree were highly susceptible to physical damage (Joyce and Li 2003).

Precooling

Hydrocooling using iced water for 2–3 h at 0–2 °C has been progressively adopted commercially in China (Joyce and Li 2002).

Postharvest physiology

Based on their respiratory and ethylene production patterns during ripening on the tree, the fruits were judged to be non-climacteric (Joyce and Li 2003). Their respiration rate reduced initially during coloration and then increased before harvest (Joyce and Li 2002). Li (2001) found that the respiration rate decreased on the first day of storage at 1 or 5 °C

then maintained a relatively low level and finally increase, which was associated with disease development. Ethylene production increased slowly with fruit ripening with an increase evident at late colour change near harvest time (Li *et al.* 2002). Fruit produced about 3.8 $\mu\text{l kg}^{-1} \text{h}^{-1}$ of ethylene at the peak rate after harvest. However, Zhang *et al.* (2005) found that fruits harvested at the immature and mature stages underwent a climacteric rise in respiration rate and ethylene production, but not in those that had been harvested fully ripe. Results were from the cultivars Biqu, Dongkui and Zaodamei. TSS increased with increased maturity but decreased over 48 h storage at 20 °C and TA decreased with increased maturity and also decreased during 48 h storage at 20 °C. In the cultivar Biqu phenylalanine ammonia-lyase activity increased in immature and mature fruit, but it decreased in ripe fruit during storage.

Storage

Its shelf life was reported by Zheng *et al.* (2004) to be very short because of its perishability and susceptibility to rot-causing pathogens. MA packaging was found to be effective in delaying senescence and disease development (Wang *et al.* 2002). Joyce *et al.* (2005) reported that CA storage was not used commercially in China but atmospheres with low CO₂ and 15% O₂ delayed accumulation of active oxygen radicals, prolonged storage life and maintained quality of the cultivar Buji compared to storage in air (Xi *et al.* 2001). Qi *et al.* (2003) found that the optimum conditions for keeping the freshness of the fruits was 2 ± 1 °C and ‘the lower the oxygen concentration, the better the inhibition effects against microorganisms’. CA storage reduced the development of soft and musty fruits by 67% after 22 days storage at 5 °C compared to those stored in air. This effect was attributed to a reduction in ethylene production.

Diseases

Postharvest pathogens were reported to cause major losses in arbutus berries in China. During their storage and shipment, decay losses were mainly caused by *Penicillium citrinum* Thom and *Verticillium dactylophila* (Peck) Hughes. Chemical fungicides have been traditionally used to control these pathogens

(Joyce *et al.* 2005). Zheng *et al.* (2004) tested different preparations of the biocontrol yeast *Cryptococcus laurentii* and found that washed cells provided the best protection against decay and it was dose dependent. It was also effective in controlling decay caused by *P. citrinum* and *V. abielina* during storage at 4 °C. The efficacy of *Cryptococcus laurentii* was enhanced by the addition of 2% calcium chloride.

Bilimbi

Oxalidaceae

Averrhoa bilimbi L. Other common names include vinagrillo, cucumber tree and tree sorrel. Morton (1987) reported that it was perhaps native to the Moluccas and had become common throughout south eastern and southern Asia. In 1793 it was taken from Timor to Jamaica and subsequently to Cuba, Puerto Rico, Trinidad, Central America, Venezuela, Colombia, Ecuador, Surinam, Guyana, Brazil and northern Argentina. It is grown in Zanzibar and was introduced into Queensland in Australia about 1896. It is cultivated widely in Brazilian the states of Rio de Janeiro, Amazonas, Pará and Santa Catarina. Bilimbi fruits are very sour and are used in the production of vinegar, wine and pickles and in the preparation of Hindu dishes. The mature fruits can be eaten fresh or processed into jams and jellies. Medicinal uses attributed to bilimbi include mixtures against coughs, mumps, rheumatism, pimples and scurvy. The tree can grow up to 18 m in height and has a short trunk dividing into a number of upright branches. The flowers are small, fragrant, yellowish green or purplish marked with dark-purple and are borne in small panicles emerging directly from the trunk and oldest, thickest branches and some twigs. The fruit is ellipsoid, obovoid or nearly cylindrical, faintly five-sided, 4–10 cm long, capped by a thin, star-shaped calyx at the stem end and tipped with five hair-like floral remnants at the apex. The fruit is crisp when unripe, turns from bright green to yellowish green, ivory or nearly white when ripe. The skin is glossy, very thin, soft and tender, and the flesh green, jelly-like, juicy and extremely acid. Fruits contain perhaps six or seven flattened, disc-like seeds about 6 mm wide, smooth and brown (Morton 1987). The chemical content was given by Morton (1987) in Table 68.

Table 68 The composition of bilimbi fruit from analyses from Nicaragua and the Philippines for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	94.2–94.7 g	Iron	1.01 mg
Protein	0.61 g	Carotene	0.035 mg
Fibre	0.6 g	Thiamine	0.010 mg
Ash	0.31–0.40 g	Riboflavin	0.026 mg
Calcium	3.4 mg	Niacin	0.302 mg
Phosphorus	11.1 mg	Ascorbic acid	15.5 mg

Harvesting

de Lima *et al.* (2001) investigated the effects of harvest maturity stages from half mature to fully mature on their physicochemical characteristics. They found that ripe fruits had the highest levels of total soluble solids and vitamin C and lowest levels of oxalic acid.

Postharvest physiology

Guadarrama and González (2009) reported that it was a climacteric fruit and ripening occurred in a few days after harvest. Ripening mainly involved a series of changes characterized by softening and changes of colour. They found that there was greater activity of pectinmethylesterase at pH between 5 and 11 and at the green stage and showed an optimal temperature of 30 °C and the maximum activity to pH 7. There was no detectable activity of cellulase during ripening and pectic substances in cell walls underwent modifications because of the action of pectinmethylesterase and polygalacturonase.

Storage

The fruits are harvested by hand, singly or in clusters. They need gentle handling because of the thin skin. They cannot be stored for more than a few days in ambient conditions. de Souza *et al.* (2008) found that fruit had a postharvest life of 9 days when stored in PVC bags at 10 ± 1 °C and 95% r.h., but there were reductions in ascorbic acid, TA and flesh firmness.

Biriba

Annonaceae

Rollinia spp. There are some 50 species of *Rollinia* including Biriba (*R. pulchrinervis* A. DC.), wild

soursop and wild sugar apple (*R. mucosa* (Jacq.) Baill.). In other work Biriba was identified as *R. mucosa* and *R. deliciosa* Saff. It can be found in the wild from Peru and northern Argentina, Paraguay and Brazil and northward to Guyana, Venezuela, Colombia and southern Mexico. It is also found in the West Indies including Trinidad, the Lesser Antilles including Guadeloupe, Martinique and St Vincent and Puerto Rico and Hispaniola. It is cultivated in Peru, Brazil and western Amazonia (Morton 1987). It is a fast growing tree up to 15 m in height. The flowers are yellowish and hermaphrodite. The fruit are greenish to yellow and conical to heart-shaped or oblate up to 15 cm in diameter. The pulp is white, mucilaginous, translucent, juicy, subacid to sweet when ripe and contains numerous black seeds. They have been reported to rival cherimoya (*Annona cherimola*) in flavour (Kennard and Winters 1960, Morton 1987).

R. mucosa, *R. papilionella*, *R. emarginata* *R. emarginata* *R. ulei* and *R. deliciosa* are acetogenin-producing plants. The annonaceous acetogenins are a series of apparently polyketide-derived fatty acid derivatives that possess tetrahydrofuran rings and a methylated γ -lactone (sometimes rearranged to a methyl ketolactone) with various hydroxyl, acetoxy, and/or ketoxy groups along the hydrocarbon chain. They exhibit a broad range of potent biological activities including cytotoxic, antitumour, antimalarial, antimicrobial, immunosuppressant, antifeedant and pesticidal (Rupprecht *et al.* 1990). Forty-two volatile components were isolated from the pulp of *R. mucosa*, grown in Cuba, of which the major volatiles were α -pinene, β -pinene and β -caryophyllene (Pino 2000). The chemical content was given by Morton (1987) in Table 69.

Table 69 The composition of biriba fruit from Brazil for 100 g⁻¹ fresh weight (source: Morton 1987)

Calories	80 kcal	Iron	1.2 mg
Moisture	77.2 g	Vitamin B1	0.04 mg
Protein	2.8 g	Vitamin B2	0.04 mg
Lipids	0.2 g	Niacin	0.5 mg
Glycerides	19.1 g	Ascorbic acid	33.0 mg
Fibre	1.3 g	Lysine	316 mg
Ash	0.7 g	Methionine	178 mg
Calcium	24 mg	Threonine	219 mg
Phosphorus	26 mg	Tryptophan	57 mg

Biale and Barcus (1970) in experiments with Amazonian fruits showed that *R. orthopetala* was a climacteric fruit. In South America, the fruit is harvested when still green and hard to facilitate transport to markets where they gradually turn yellow and soften. When the fruit is fully ripe, handling may cause the wart-like protuberances on the skin to turn brown or black (Morton 1987).

Bitter melon

Cucurbitaceae

Momordica charantia L. also called balsam pear, bitter gourd and bitter squash. Purseglove (1975) reported that its origin was the Old World and it was taken to Brazil in the early slave trade and is now widespread throughout the tropics. It is a tropical and sub-tropical herbaceous climbing vine up to 5 m long. Each plant bears separate yellow male and female flowers. The fruit is oblong with a warty exterior and is hollow in cross section, with a relatively thin layer of flesh surrounding a central seed cavity filled with large, flat seeds and pith. The fruit is most often eaten green or as it is beginning to turn yellow when its flesh is crunchy and watery in texture but bitter and the skin is tender and edible. The seeds and pith are white in unripe fruits. As the fruit ripens skin becomes tougher, bitterer and not palatable, but the pith becomes sweet and red and it can be eaten uncooked and is used in some salads in Southeast Asia. The fruit eventually turns orange and mushy and splits into segments that curl back to expose seeds covered in bright red pulp.

It has low ethylene production but high sensitivity to ethylene in storage. Their respiration rate was given as 7.4 at 0 °C, 14.8 at 5 °C, 27.7 at 10 °C, 49.9 at 15 °C and 62.8 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Zong *et al.* 1993, SPLFC 2001). Zong *et al.* (1993) reported that they were subject to chilling injury. Symptoms included pitting that can develop into sunken brown spots and darkening as well as internal breakdown of tissue and increased decay when they were removed from storage below 10 °C to ambient conditions. Zong *et al.* (1993) and SPLFC (2001) recommended storage at 10–12 °C and 85–90% r.h. for 14–21 days and at 20 °C for 3–5 days. Controlled atmosphere storage recommendation was 10–12 °C

and 85–90% r.h. with 2–3% O₂ and 5% CO₂ (SPLFC 2001).

Blackberry

Rosaceae

Rubus ulmifolius Schott and *R. fruticosus* L.H. Bailey. They are also called brambles and other species include *R. articus* L. the Artic Bramble. It is a prickly climbing plant whose fruit is a collection of drupes. Its freezing point was given as –2.2 to –1.4 by Wright (1942). When fully mature they have a soluble solids content of about 9% and an acid content of 0.68–1.84% weight for weight and a sugar:acid ratio of 2.8 (Hulme 1971). Esters and terpenes were the most abundant aromatic fractions, but no significant effect was found in treatment with methyl jasmonate in combination with ethanol on total volatile compounds (Blanch *et al.* 2012). The chemical content was given by USDA (2012) in Table 70.

Harvesting

They are normally harvested by hand with the receptacle in place when the fruit has turned black and are fat, juicy and shiny (Figure 84).

Table 70 The composition of blackberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	88.15 g	Thiamine	0.020 mg
Energy	43 kcal	Riboflavin	0.026 mg
Protein	1.39 g	Niacin	0.646 mg
Total lipid (fat)	0.49 g	Vitamin B-6	0.030 mg
Carbohydrate, by difference	9.61 g	Folate	25 µg DFE
Total dietary fibre	5.3 g	Vitamin B-12	0.00 µg
Total sugars	4.88 g	Vitamin A	11 µg RAE
Calcium	29 mg	Vitamin A	214 IU
Iron	0.62 mg	Vitamin E	1.17 mg
		(α-tocopherol)	
Magnesium	20 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	22 mg	Vitamin D	0 IU
Potassium	162 mg	Vitamin K	19.8 µg
		(phyloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.014 g
Zinc	0.53 mg	Fatty acids, total monounsaturated	0.047 g
Total ascorbic acid	21.0 mg	Fatty acids, total polyunsaturated	0.280 g



Figure 84 Blackberry showing developing fruit and fruit ready for harvesting. See colour plate section.

Precooling

Forced air cooling with high humidity was the most acceptable method, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling less suitable (MAFF n.d.).

Postharvest physiology

The fruit is classified as non-climacteric. Hulme (1971) observed that the fruit continued to change in colour during the first 24 h after harvesting. Ethylene production was reported to vary with cultivar and can be as little as 0.1 µl kg⁻¹ h⁻¹ or as high as 2 µl kg⁻¹ h⁻¹ (Burdon and Sexton 1993). Perkins-Veazie (2002c) reported that stimulation of *Botrytis cinerea* (grey mould) growth can occur on blackberries in the presence of ethylene. She also found that the respiration rate for the cultivars Navaho, Shawnee and Choctaw at 20 °C was 100–130 mg CO₂ kg⁻¹ h⁻¹. Respiration rate was generally high (Table 71).

Storage

Refrigerated storage recommendations include

- –0.6 to 0 °C and 85–90% r.h. for 5–7 days (Phillips and Armstrong 1967);

Table 71 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Bedford Giant blackberries (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	22	33	62	75	155
In 3% O ₂	15		50		125

- -1 to 0 °C and 90% r.h. for 5–7 days (Anonymous 1967);
- -0.6 to 0 °C and 90–95% r.h. for 2–3 days (Lutz and Hardenburg 1968);
- 0 °C and 90% r.h. for 10 days for Bedford Giant (Robinson *et al.* 1975);
- -0.5 and 90–95% r.h. for 2–3 days (SeaLand 1991);
- -0.5 to 0 °C and greater than 90% r.h. for 2–14 days, depending on cultivar (Perkins-Veazie 2002c).

Controlled atmosphere storage

Respiration rate was strongly affected not only by temperature but also by the O₂ level in the storage atmosphere (Table 71). This might indicate that CA storage with reduced O₂ could be beneficial and the effect of reduced O₂ was similar at all the storage temperatures. Kader (1989) recommended 0–5 °C with 10–15% CO₂ and 5–10% O₂. In other work high levels of CO₂ were recommended e.g. 20–40% CO₂ at 20 °C were reported to be used to maintain the quality of machine-harvested blackberries for processing during short-term storage (Hardenburg *et al.* 1990). Hulme (1971) also found that they retained their flavour well for 2 days if they are cooled rapidly and stored in an atmosphere containing up to 40% CO₂.

Disease

The most common postharvest diseases were reported to be grey mould (*Botrytis cinerea*) and rhizopus rot (*Rhizopus stolonifer*) (Perkins-Veazie 2002c).

Blackcurrant

Grossulariaceae, Saxifragaceae

Ribes nigrum L. They are native of Europe where they have been cultivated for more than 400 years. John

Tradescant imported blackcurrants plants into the United Kingdom from Holland in 1611. In 1826 the Royal Horticultural Society recognized five black currant cultivars in the United Kingdom: Black Naples, Black Grape, Common Black, Wild Black and Russian Grape (Brennan 1996). They have become popular and a major crop in Britain since the blackcurrant juice drink Ribena® was developed in the 1930s. Using a pectinase process V.L.S. Charley working at the Long Ashton Horticulture Research Station in the United Kingdom had developed a syrup from blackcurrants for inclusion in milk shakes. A local company, H.W. Carter, used the syrup to make a fruit drink. They launched the drink in 1938 under the name of Ribena. The company was taken over by Beecham Products (UK) Limited and Dr Charley continued as a consultant. Production was considerably expanded in the 1960s and mechanical harvesting of blackcurrants was developed in the 1970s. Ribena is currently owned by GlaxoSmithKline. By 2008 there were some 2300 ha of blackcurrants in production in Britain producing about 14,000 tonnes, which had a farm gate value of approximately £8 million.

The fruits are small and they turn shiny and black when ripe and contain many small seeds. They are borne in clusters called strings and the fruit matures in order along the strings with the first one nearest the pedicel and the last being the terminal fruit. Blackcurrant fruit are more astringent than redcurrants but have a distinct aroma that makes them suitable for processed products. When mature they had a total sugar content of about 7.9% and a total solids content of 19.7% made up of 13.8% soluble solids and 5.9% insoluble solids and sugar: acid ratio of 2.1 (Hulme 1971). It has exceptional antioxidant capacity that exceeds many other berry fruit in terms of radical scavenging activity (Benvenuti *et al.* 2004). Key antioxidant components include ascorbic acid at about 100–300 mg 100 ml⁻¹ (Walker *et al.* 2010). They are also high in polyphenolic antioxidants at about 800 mg 100 g⁻¹ (Moyer *et al.* 2002). The polyphenol component consists of a range of compounds including anthocyanins, flavonols, flavan-3-ols and hydroxycinnamic acid derivatives (Gavrilova *et al.* 2011). The dominant anthocyanins were glucosides and rutinoides of delphinidin and cyanidin, although minor quantities of petunidin, peonidin and anthocyanin–flavonol condensation

Table 72 The composition of European blackcurrant fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	81.96 g	Total ascorbic acid	181.0 mg
Energy	63 kcal	Thiamine	0.050 mg
Protein	1.40 g	Riboflavin	0.050 mg
Total lipid (fat)	0.41 g	Niacin	0.300 mg
Carbohydrate, by difference	15.38 g	Vitamin B-6	0.066 mg
Calcium	55 mg	Vitamin B-12	0.00 µg
Iron	1.54 mg	Vitamin A	12 µg RAE
Magnesium	24 mg	Vitamin A	230 IU
Phosphorus	59 mg	Vitamin E	1.00 mg
		(α -tocopherol)	
Potassium	322 mg	Fatty acids, total saturated	0.034 g
Sodium	2 mg	Fatty acids, total monounsaturated	0.058 g
Zinc	0.27 mg	Fatty acids, total polyunsaturated	0.179 g

derivatives have also been identified (Gavrilova *et al.* 2011). The chemical content was given by USDA (2012) in Table 72.

Harvesting

It is normal to harvest the whole cluster of fruit together, even though they will contain under mature fruit (Hulme 1971). They can be picked by hand, but with the great demand for blackcurrant juice they are mainly machine harvested. These are usually tractor-mounted machines that have combing fingers that are run up the stems pulling off the fruit bunches, as well as a high proportion of the leaves (Figure 18). This is achieved by small amplitude high-frequency vibration by the rubber fingers that are mounted on a vertical drum that rotates at the same velocity as the harvester moves forward. The fruit may subsequently be separated from the leaves by blowers and the juice extracted. In other cases the fruit is taken straight from the field and passed through a press and filter system to remove leaves and other materials. An important factor to be considered with mechanical harvesting is to breed cultivars whose fruit all mature at the same time (Hitchcock 1973, Williams 1975).

Precooling

Forced air cooling with high humidity was the most acceptable, air cooling in a conventional cold store

was suitable and hydrocooling and vacuum cooling less suitable (MAFF n.d.).

Storage

Hulme (1971) found that fruit held for 24 h at ambient temperatures continued to darken in colour and lost some 3% in weight and 7% in ascorbic acid content on a fresh weight basis. Refrigerated storage recommendations include

- -1 to 0 °C and 90% r.h. for 1–2 weeks (Anonymous 1967);
- -0.6 to 0 °C and 90–95% r.h. for 1–2 weeks (Lutz and Hardenburg 1968);
- -0.5 to 0 °C and 90–95% r.h. for up to 4 weeks (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1990);
- -0.5 °C and 90–95% r.h. for 7–14 days (SeaLand 1991).

Controlled atmosphere storage

Respiration rate was reduced at all temperatures tested in 3% O₂ in the storage atmosphere, but particularly at the highest temperature (Table 73). Smith (1957, quoted by Hulme 1971) recommended 2 °C with 50% CO₂ for 1 week followed by 25% CO₂ for the remainder of the storage period. Stoll (1972) recommended 2–4 °C with 40–50% CO₂ and 5–6% O₂. After storage at 18.3 °C with CO₂ levels of 40% for 5 days the fruit had a subsequent shelf life of 2 days with 2–3% of the fruit being unmarketable due to rotting (Wilkinson 1972). Skrzynski (1990) described experiments where fruits of the cultivar Roodknop were held at 6–8 °C for 24 h and then transferred to 2 °C for storage for 4 weeks in one of the following: 20% CO₂ with 3% O₂, 20% CO₂ with 3% O₂ for 14 days and then 5% CO₂ with 3% O₂, 10% CO₂ with 3% O₂ and 5% CO₂ with 3% O₂ or ambient air. The best retention of total ascorbic acid content was obtained in both treatments with 20% CO₂. In years with favourable weather preceding the harvest, storage in 20% CO₂ completely controlled the occurrence of moulds caused mainly by *Botrytis*, *Mucor* and *Rhizopus* spp.

For juice manufacture, storage of fruit at 2 °C with 50% CO₂ for 7 days followed by a further 3 weeks with 25% CO₂ was recommended by Smith (1957, quoted

Table 73 Effects of temperature and reduced O₂ level on the respiration rate as CO₂ production in milligram per kilogram per hour of blackcurrants (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	16	27	39	90	130
In 3% O ₂	12		30		74

by Hulme 1971). There was an accumulation of alcohol and acetaldehyde but the juice quality was not affected. Fruit stored in CO₂ levels of 40% at 18.3 °C for 5 days had a subsequent shelf life of 2 days with 2–3% of the fruit being unmarketable due to rotting (Wilkinson 1972). Fruits of the cultivar Rosenthal were stored at 1 °C in either a controlled atmosphere of 10, 20 or 30% CO₂ all with 2% O₂ or a high CO₂ environment of 10, 20 or 30% CO₂ all with greater than 15% O₂. The optimum CO₂ concentration was found to be 20%. Ethanol accumulation was higher under controlled atmosphere storage than a higher CO₂ environmental condition. Fruits could be stored for 3–4 weeks under controlled atmosphere storage or high CO₂ environmental conditions, compared 1 week, for fruits stored at 1 °C in a normal atmosphere (Agar *et al.* 1991).

CA storage can affect the nutrient content of blackcurrants. Harb *et al.* (2008a) found that storage of the cultivar Titania in air for up to 6 weeks did not significantly affect total terpene volatiles, which were similar to those in freshly harvested berries. They found that decreasing O₂ and increasing CO₂ levels retarded their capacity to synthesize terpenes for 3 weeks but during storage for an additional 3 weeks led to a partial recovery. However, storage in 18% CO₂ + 2% O₂ resulted, in most cases, in a lower biosynthesis of volatile constituents compared to storage in air for 6 weeks. Non-terpene compounds, mainly esters and alcohols, were also increased in fruit during storage in air compared to those in CA storage where there was an initial reduction, but they later recovered.

Diseases

Skrzynski (1990) reported the occurrence of moulds caused mainly by *Botrytis*, *Mucor* and *Rhizopus* spp. on fruit. Fungicide treatment in the field with Signum® or Platoon® not only reduced the incidence of foliar disease but also enhanced the total polyphenol and anthocyanin content of the fruit

(Nwankno *et al.* 2012). Xu *et al.* (2008) inoculated fruit of the cultivars Baldwin and Ben Hope with *Botrytis cinerea* at different growth stages and then incubated them under different initial conditions of 10, 15, 20 or 25 °C each with four wet periods of 4, 8, 12 or 24 h, respectively. Infection of fruit was not significantly affected by the temperature and duration of wetness but the two cultivars differed significantly in their responses to *B. cinerea* infection depending on the fruiting stage at the time of inoculation. Inoculation of young fruitlets resulted in nearly 50% of fruits aborted on Baldwin, compared to about 10% on Ben Hope. Inoculation of fruit near harvest resulted in significantly fewer fruit aborted. The incidence of latent infection decreased with increasing fruit age at the time of inoculation.

Black sapote

Ebenaceae

Diospyros digyna Jacq., *D. ebenaster* Retz. It originated in Mexico and there is evidence of its cultivation there in the period 5000–3000 BCE (Purseglove 1975). The fruits have a thin skin that becomes olive green as they mature turning brown or black as they ripen. They are globular, usually weighing about 200–250 g and up to 12 cm in diameter and have a soft sweet pulp that is dark brown in colour.

The main factor limiting storage was softening and their shelf life at 20 °C and 85% r.h. was 13 days with 11–16% weight loss (Nerd and Mizrahi 1993). Miller *et al.* (1997) found that some fruit stored at 10 °C for 10 or 15 days showed abnormal ripening and most fruit stored at 1 or 5 °C did not ripen normally or failed to ripen. They also showed that they will tolerate irradiation at 0.15 kGy, which can extend their storage life but abnormal ripening occurred with some fruit when treated at 0.3 kGy. Refrigerated storage recommendations include

- 12.8 °C and 85–90% r.h. for 14–21 days (SeaLand 1991);
- 10 °C and 85% r.h. for 29 days with 11–16% water loss (Nerd and Mizrahi 1993);
- 10 °C for 7 days and then transferred to 25 °C fruits ripened normally (Miller *et al.* 1997);
- 15, 20 or 25 °C for up to 15 days and then transferred to 25 °C ripened normally (Miller *et al.* 1997).

Fruits wrapped in plastic film had 40–50% longer storage life at 20 °C than fruits not wrapped (Nerd and Mizrahi 1993).

Blueberry, bilberry

Vacciniaceae

Vaccinium spp. There are several species called blueberry and bilberry including *V. deliciosum* Piper (Cascade bilberry), *V. darrowi* Camp. (Darrow's blueberry), *V. cespitosum* Michx. (Dwarf bilberry), *V. corymbosum* L. (Highbush or Northern blueberry), *V. angustifolium* Aiton (Lowbush blueberry), *V. boreale* I.V. Hall & Aalders (Northern blueberry), *V. ashei* Rehder (Rabbiteye) and *V. myrtillus* L. (Whortleberry or Bilberry) (Hulme 1970). Cultivars are mostly hybrids among *V. corymbosum*, *V. ashei*, *V. angustifolium* and *V. darrowi*. These are very different from the wild blueberries and individual fruit may be four times as big. In the past, the names blueberry and bilberry were applied to any of these berries, but blueberry is now commonly used only to the cultivated fruits and bilberry to wild fruit. Other names include whortleberry and huckleberry. *V. ovatum* is also referred to as *Huckleberry* and is native to the western coast of North America from northern California to British Columbia. Total world production in 2010 was estimated by FAO (2013) as 313,573 tonnes.

Vaccinium are low scrubby plants. The fruit is a berry and usually deep purple or red to almost black in colour. Bilberry produces single or pairs of berries (Figure 85) on the bush instead of clusters in the blueberry. In Scotland, bilberries are sometimes known as blaeberrys. The bilberry grows all over northern Europe and is very popular in Sweden. Being fairly acidic, they are usually cooked unlike the blueberry, which can be eaten raw or cooked. In North America, bilberries are sometimes called whortleberries or huckleberries and are generally distributed in the far northern mountainous parts of New England and the Lake Superior region. In an analysis of *V. myrtillus* for anthocyanin content, cyanidin was found in the highest quantities with a mean amount 0.053 µg ml⁻¹. Delphinidin and petunidin were found in quantities 2.5-fold lower than cyanidin, and malvidin and peonidin were found in the smallest quantities. Malvidin was found in



Figure 85 Bilberry growing wild in West Yorkshire in the United Kingdom. See colour plate section.

Table 74 The composition of blueberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	84.21 g	Thiamine	0.037 mg
Energy	57 kcal	Riboflavin	0.041 mg
Protein	0.74 g	Niacin	0.418 mg
Total lipid (fat)	0.33 g	Vitamin B-6	0.052 mg
Carbohydrate, by difference	14.49 g	Folate	6 µg DFE
Total dietary fibre	2.4 g	Vitamin B-12	0.00 µg
Total sugars	9.96 g	Vitamin A	3 µg RAE
Calcium	6 mg	Vitamin A	54 IU
Iron	0.28 mg	Vitamin E (α-tocopherol)	0.57 mg
Magnesium	6 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	12 mg	Vitamin D	0 IU
Potassium	77 mg	Vitamin K (phylloquinone)	19.3 µg
Sodium	1 mg	Fatty acids, total saturated	0.028 g
Zinc	0.16 mg	Fatty acids, total monounsaturated	0.047 g
Total ascorbic acid	9.7 mg	Fatty acids, total polyunsaturated	0.146 g

the highest amounts in blueberries collected in Sweden, which had 1.5-fold higher than amounts of petunidin and delphinidin (Burdulis *et al.* 2007). The chemical content was given by USDA (2012) in Table 74.

Preharvest treatments

The cultivars O'Neal and Bluecrop plants of *V. corymbosum* were fertilized with calcium sulphate at 0.06 kg

m⁻². On the following season the fruit were harvested when they were completely blue and stored at 2 °C for 23 days. At harvest fruit that had been fertilized with calcium sulphate had 10% more calcium content within the cell wall in both cultivars and both had less softening and weight loss in storage. Their respiration rate increased during storage, but this increment was lower in calcium sulphate-treated fruit. Calcium sulphate treatment did not affect their colour, anthocyanins, acidity or sugars (Angeletti *et al.* 2010).

Harvesting

They should be harvested when they are fully coloured and handling should be minimized as they are very delicate and damage easily and the bloom on the fruit surface can be destroyed. The berries are very small and have to be picked by hand, which is very laborious. Mixtures of soft ripe and hard ripe fruits should be avoided as the over-ripe ones can speed deterioration of all the fruit (Lutz and Hardenburg 1968).

Over the row, self-propelled vibrating machines have been developed for harvesting blueberries (Nelson 1966). These machines are fitted with collecting pans and conveyer belts and are capable of harvesting fruit from 1½ acres per hour. Machine-harvested blueberries had a harvesting cost of only 76% of hand-harvested fruit, but 50% of the crop was lost during mechanical harvesting (Liner 1971). In subsequent work the cost of harvesting and sorting machine-harvested blueberries for processing was 44% of the cost of hand harvesting and packaging fruit for the fresh market (Safley 1985). Blueberry bushes, which are regularly mechanically harvested, yielded 6–42% less fruit than bushes that had been hand picked (Mainland 1971). Machine-harvesting blueberries caused 50 times more damage to canes than hand-harvesting and machine-harvested fruit were 10–30% softer and developed 11–41% more decay than hand-harvested fruit (Mainland *et al.* 1975). Nunez-Barrios *et al.* (2005) found that mechanical harvesting increased fruit respiration rate both at 1 °C and ambient storage temperatures and hand-harvested fruits had better quality. They also reported that firmness of mechanically harvested blueberries was decreased by 30.2% during storage compared to those that were hand harvested. Mechanically harvested berries stored at

22 °C had a weight loss rate of 2.3% day⁻¹, compared with 0.8% day⁻¹ for those that were harvested by hand. Mechanically harvested blueberries could be maintained in good condition at 20 °C for up to 2 days in high CO₂ atmospheres (Morris *et al.* 1981).

Prestorage treatments

Changes in the marketable percentage of the cultivars Burlington and Coville after storage for up to 12 weeks at 0 ± 1 °C were not affected by pretreatment for 24 h at 20 °C with 1-MCP at rates up to 400 nl L⁻¹ (DeLong *et al.* 2003). Duan *et al.* (2011) reported that coating the blueberry cultivars Duke and Elliott in acid-soluble chitosan, water-soluble chitosan or water-soluble chitosan + acid-soluble chitosan helped to reduce the decay during storage at room temperature of 20 °C.

Postharvest physiology

The fruit is classified as climacteric (Windus *et al.* 1976). Ethylene production was 0.5–2 µl kg⁻¹ h⁻¹ for northern highbush and 10 µl kg⁻¹ h⁻¹ for rabbiteye and stimulation of *Botrytis cinerea* growth can occur on blueberries in the presence of ethylene. Nunez-Barrios *et al.* (2005) found that the respiration rate was decreased by 73.8% at 1 °C compared to ambient temperature of 22 °C. Respiration rate was also given by Perkins-Veazie (2002a) in Table 75. Ferraz *et al.* (2001) studied the effects of a non-destructive measurement to determine resistance to a small deformation made in the elastic region of the berry. Individual blueberries were compressed up to 1.25 mm between two parallel plates to obtain force–deformation curves and the curves they obtained could be used as indicators of fruit firmness over time. They concluded that this technique showed promise for evaluating postharvest quality changes in blueberries.

Storage

Berries stored at 4.4 °C or above gradually developed a tough texture (Lutz and Hardenburg 1968). The cultivar Bluecrop stored at 12 °C had high scores for taste, aroma, bitter flavour and flavour intensity and had a high percentage TA. Fruits stored at 4 °C scored high for sweet taste, colour (more blue), acidic taste,

Table 75 Respiration rate of blueberry fruit (source: adapted from Perkins-Veazie 2002a)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	2–10
4–5	9–12
10	23–35
15–16	34–62
20–21	52–87
25–27	78–124

blueberry flavour, firmness, crispness and juiciness (Rosenfeld *et al.* 1999). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 1–2 days (Mercantilia 1989). Refrigerated storage recommendations include

- –0.6 to 0 °C and 90 to 95% r.h. for 2 weeks or with some loss of quality for 4–6 weeks (Anonymous 1968, Lutz and Hardenburg 1968);
- –0.5 to 0 °C and 90 to 95% r.h. for about 2 weeks (Hardenburg *et al.* 1990);
- 0 °C and 90% r.h. for 10–14 days (Mercantilia 1989);
- 0 °C and 90 to 95% r.h. for 2–4 weeks (Snowdon 1990);
- 0 °C and 90 to 95% r.h. for 21–28 days (red whortleberry) (SeaLand 1991);
- –0.5 and 90 to 95% r.h. for 10–18 days (blueberry) (SeaLand 1991);
- –0.5 to 0 °C with greater than 90% r.h. for up to 2 weeks for lowbush, northern and southern highbush and up to 4 weeks for rabbiteye (Perkins-Veazie 2002a).

Controlled atmosphere storage

The storage of fresh blueberries for 7–14 days at 2 °C in an atmosphere in 15% CO₂ delayed their decay by 3 days after they had been returned to ambient temperature compared to storage in air at the same temperature (Ceponis and Cappellini 1983). They also showed that storage in 2% O₂ had no added effect over the CO₂ treatment. Kader (1989) recommended 0–5 °C with 15–20% CO₂ and 5–10% O₂ for optimum storage. Ellis (1995) recommended 0.5 °C and 90–95% r.h. with 10% O₂ and 10% CO₂ for ‘medium-term’ storage. Storage at or below 5 °C with 10–15% CO₂ + 1–10% O₂ maintained firmness and acidity and decreased decay for

up to 6 weeks for rabbiteye, highbush and lowbush blueberries (Perkins-Veazie 2002a). The optimum atmosphere for the storage of the cultivar Burlington was 0 °C with 15% O₂ + 10% CO₂ in which fruit maintained good quality for over 6 weeks (Forney *et al.* 2003). After 6 weeks storage at 0 °C in 15% O₂ + 25% CO₂ the concentration of ethanol was about 18 times higher and ethyl acetate was about 25 times higher than in those stored in 15% O₂ + 0 or 15% CO₂ (Forney *et al.* 2003). Harb and Streif (2006) successfully stored the cultivar Bluecrop for up to 6 weeks in 12% CO₂ + 21% O₂, which retained fruit firmness, had low decay and the absence of off-flavour. Fruits of the cultivar Duke could be kept in air at 0–1 °C in acceptable condition for up to 3 weeks. However, for storage for up to 6 weeks, up to 12% CO₂ + 18–21% O₂ was found to give the best results. Storage in 6–12% CO₂ maintained their firmness while those stored in greater than 12% CO₂ rapidly softened at both 2% O₂ and 18% O₂ and had poorer flavour, firmness and acidity content. Also with increasing CO₂ levels the respiration rate also increased in all CO₂ levels to higher respiration rates than fruit stored in air. Chiabrando and Peano (2006) found that storage at 1 °C in 3% O₂ + 11% CO₂ for 60 days maintained fruit firmness, total soluble solids and TA better than storage in air at 3 °C and 90–95% r.h. DeEll (2002) reported that storage in 15–20% CO₂ + 5–10% O₂ reduced the respiration rate and softening, but exposure to less than 2% O₂ and/or greater than 25% CO₂ could cause off-flavours and brown discolouration, depending on the cultivar, duration of exposure and temperature. Zheng *et al.* (2003) showed that the antioxidant levels in Duke increased in 60–100% O₂ as compared with 40% O₂ or air during 35 days storage. O₂ levels of between 60 and 100% also resulted in an increase in total phenolics and total anthocyanins.

Schotsmans *et al.* (2007) found that fungal development was reduced by CA storage. After 28 days at 1.5 °C in 2.5% O₂ + 15% CO₂ the cultivars Centurion and Maru had only half as much blemished fruit compared with those stored in air. Incidence of fungal diseases, mainly caused by *Botrytis cinerea*, could be efficiently controlled by CO₂ levels over 6% (Harb and Streif 2004a). DeEll (2002) reported that 15–20% CO₂ + 5–10% O₂ reduced the growth of *B. cinerea* and other decay-causing organisms during transport

and storage. Zheng *et al.* (2003) showed that fruit stored in $\geq 60\%$ O₂ had significantly less decay. Song *et al.* (2003) showed that the percentage marketability of the cultivar Highbush was 4–7% greater than in the controls after treatment with 200 ppb O₃ for 2 or 4 days in combination with 10% CO₂ + 15% O₂.

Modified atmosphere packaging

Sealing fruit in polyethylene film box liners resulted in maintaining their turgidity and reducing weight loss during storage at 0 °C, but off-flavours developed when they were stored for about 6 weeks (Lutz and Hardenburg 1968). This seems a very long time for storage in view on the information on controlled atmosphere storage. Blueberries in non-vented clamshell containers had reduced weight loss and increased firmness compared to those in vented clamshell containers during storage at 2 °C for 1 week (Duan *et al.* 2011).

Disease

Blueberries are susceptible to grey mould, *Botrytis cinerea*, anthracnose or ripe rot, *Colletotrichum gloeosporioides* and alternaria rot caused by *Alternaria* sp. *Rhizopus stolonifer* can grow readily in fruit packs in storage above 10 °C (Perkins-Veazie 2002a). A 3-min immersion of blueberries in water at 46–55 °C reduced subsequent decay by as much as 90% but 40 °C was ineffective and greater than 55 °C injured the fruit (Burton *et al.* 1974). Cantín *et al.* (2012) reported that *Botrytis* and *Alternaria* spp. were the dominant fungal pathogens causing decay of blueberries (*V. corymbosum*) during storage, but differences in the species of decay microorganisms were found among cultivars. They found that SO₂ fumigation significantly reduced decay incidence, especially when it was followed by storage in 3% O₂ + 6% CO₂ and did not negatively affect phytochemical content or antioxidant activity of the fruit.

Camu-camu

Myrtaceae

Myrciaria dubia Kunth McVaugh synonymous with *M. paraensis* Berg and *M. spruceana* Berg. It is native to the flood plains of the Amazon region of Brazil,

Venezuela and the Rio Mazán near Iquitos in Peru. It can survive submerged in water, but it is also cultivated in non-flooding areas. It is a shrub that can grow up to 13 m high (Morton 1987) or 4–8 m in its native environment, but typically it achieves a height of 1–3 m (Hernández *et al.* 2011). The flowers are fragrant with white petals and are borne in fours in or near the leaf axils. The fruits are globular and up to about 3 cm in diameter containing up to four seeds. The pulp is white with an acid or sweet flavour and the thin skin is shiny and yellow as they develop ripening to pink, red or purple. Andrade *et al.* (2010) reported that they had high levels of ascorbic acid and the stage of maturation affected the chemical composition of fruits. Ripe fruit had lower acidity (2.7% ripe and 2.8% mid-ripe), lower ascorbic acid (1.4% ripe and 1.8% mid-ripe), higher reducing sugars (3.1% ripe and 3.0% mid-ripe), higher TSS content (8.2% ripe and 6.9% mid-ripe) and higher levels of anthocyanins (0.342 O.D. ripe and 0.149 O.D. mid-ripe). Charley (1969) reported that they had similar levels of ascorbic acids (2500 mg 100 kg⁻¹) as acerola.

Harvesting

The fruit skin turns from green to purple red during ripening. Anthocyanins increased in immature stages and decreased in ripe stages but ascorbic acid content remained stable and constant during storage at either 21 or 28 °C with 87% r.h. for 8 days (Andrade *et al.* 2010).

Postharvest physiology

The fruit was reported to be a climacteric (Carrillo *et al.* 2011) and fruit harvested at the half mature and mature stages showed a climacteric rise within 2 or 3 days of harvesting, accompanied by ethylene production from undetectable to 0.1 µl kg⁻¹ h⁻¹ (Hernández *et al.* 2011).

Storage

Silva and Andrade (1997) stored mid-ripe fruit in PVC film bags at 20 °C and 68% r.h. but found that it was not effective in maintaining ascorbic acid and anthocyanins levels. Carrillo *et al.* (2011) found that fruit harvested at the turning and the fully ripe stages

could be stored at 6 °C with good preservation of vitamin C and colour as well as reduced respiration rate better than storage at 10 or 20 °C. However, at 6 °C fruits showed chilling injury. They concluded that harvesting at the turning stage and storage at 10 °C was the most suitable in extending their postharvest life and the retention vitamin C and sugar for 8 days.

Canistel

Sapotaceae

Pouteria campechiana (HBK.) Baenhi synonymous with *P. campechiana* var. *nervosa* Baehni, *P. campechiana* var. *palmeri* Baehni, *P. campechiana* var. *salicifolia* Baehni, *Lucuma campechiana* HBK., *L. Heyderi* Standl., *L. laeteviridis* Pittier, *L. multiflora* Millsp. not A. DC., *L. nervosa* A. DC., *L. palmeri* Fernald, *L. rivicoa* Gaertn., *L. rivicoa* var. *angustifolia* Miq., *L. salicifolia* HBK., *Richardella salicifolia* Pierre, *Sideroxylon campestre* T.S. Brandeg., *Vitellaria campechiana* Engl. and *V. salicifolia* Engl. They are also called egg fruit, ti-es, huevo vegetal and jácana. It apparently occurs wild only in southern Mexico, Belize, Guatemala and El Salvador and is cultivated in these countries and in Costa Rica, Nicaragua and Panama, Puerto Rico, Jamaica, Cuba, the Bahamas and Florida (Morton 1987).

The tree is erect and up to 8 m tall, but it may, in favourable situations, reach height of 27–30 m with brown, furrowed bark and abundant white, gummy latex. The fruit may be almost round, with or without a pointed apex or curved beak, or may be ovoid, or spindle shaped and up to 12 cm long and 8 cm wide. When unripe the fruit has green skin containing hard and gummy pulp containing up to 3 or 4 dark brown shiny seeds. On ripening, the skin turns yellow or orange-yellow. The yellow flesh is relatively firm and mealy with a few fine fibres. The flavour is sweet and more or less musky. Fruit are usually eaten fresh or used in puddings or made into jam (Kennard and Winters 1960, Morton 1987). The chemical content is given in Table 76.

If kept at room temperature, the fruits will soften to eating-ripe in 3–10 days. They should not be allowed to become too soft and mushy before eating. Freshly harvested, hard fruits have been successfully shipped from Florida to New York City and Philadelphia.

Table 76 Composition per 100 g⁻¹ of edible portion of canistel from Cuba (source: Morton 1987)

Calories	138.8	Iron	0.92 mg
Moisture	60.6 g	Carotene	0.32 mg
Protein	1.68 g	Thiamine	0.17 mg
Fat	0.13 g	Riboflavin	0.01 mg
Carbohydrates	36.69 g	Niacin	3.72 mg
Fibre	0.10 g	Ascorbic acid	58.1 mg
Ash	0.90 g	Tryptophan	28 mg
Calcium	26.5 mg	Methionine	13 mg
Phosphorus	37.3 mg	Lysine	84 mg

Capulin

Rosaceae

Prunus salicifolia HBK., synonymous with *P. capuli* Cav., *P. serotina* var. *salicifolia* Koehne. Other common names include Cerezo Criollo, Wild Cherry and Black Cherry. It is native and common in Mexico from Sonora to Chiapas and Veracruz, and possibly indigenous to western Guatemala, where it has been cultivated since early times and other parts of Central America and in Colombia, Ecuador, Peru and Bolivia. The fruit is an important food, not only of the Indians, but also of all the inhabitants, and it was at times a mainstay of the invading Spaniards. It was introduced into the cool medium elevations of the Philippines in 1924. The tree requires a subtropical to subtemperate climate and grows naturally at elevations between 1200 and 3400 m (Morton 1987).

The tree is erect up to 12–15 m in height with a short, stout trunk up to 0.9 m in diameter. Flowers, borne in slender, pendent racemes about 2 cm wide with white petals. The aromatic fruit is round 1–2 cm wide, with red or nearly black, rarely white or yellowish, smooth, thin, tender skin and pale-green, juicy pulp of sweet or acid, agreeable, but slightly astringent flavour with a single seed. The chemical content was given by Morton (1987) in Table 77.

Carambola

Oxalidaceae

Averrhoa carambola L. Other common names include jalea and star fruit. It is a native of Indochina but is grown widely throughout the tropics and the warmer areas of the subtropics. It is an attractive tree up to about 12 m high with rose-coloured flowers borne

Table 77 The composition of capulin fruit made in Guatemala and Ecuador for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	76.8–80.8 g	Phosphorus	16.9–24.4 mg
Protein	0.105–0.185 g	Iron	0.65–0.84 mg
Fat	0.26–0.37 g	Carotene	0.005–0.162 mg
Fibre	0.1–0.7 g	Thiamine	0.016–0.031 mg
Ash	0.56–0.82 g	Riboflavin	0.018–0.028 mg
Calcium	17.2–25.1 mg	Niacin	0.640–1.14 mg
		Ascorbic acid	22.2–32.8 mg

Table 78 The composition of carambola fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	91.38 g	Thiamine	0.014 mg
Energy	31 kcal	Riboflavin	0.016 mg
Protein	1.04 g	Niacin	0.367 mg
Total lipid (fat)	0.33 g	Vitamin B-6	0.017 mg
Carbohydrate, by difference	6.73 g	Folate	12 µg DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 µg
Total sugars	3.98 g	Vitamin A	3 µg RAE
Calcium	3 mg	Vitamin A	61 IU
Iron	0.08 mg	Vitamin E	0.15 mg
		(α-tocopherol)	
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	12 mg	Vitamin D	0 IU
Potassium	133 mg	Vitamin K	0.0 µg
		(phyloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.019 g
Zinc	0.12 mg	Fatty acids, total monounsaturated	0.030 g
Total ascorbic acid	34.4 mg	Fatty acids, total polyunsaturated	0.184 g

in clusters from the leaf axils or laterally from the stems. The fruit are oval or elliptical fleshy berries with distinct ridges giving them a star shape in cross section and are up to about 15 cm long. They vary in weight from less than 80 g to more than 200 g (Campbell 1989). The skin is shiny, green as it develops and a bright yellow when fully mature. The flesh is crisp, juicy and aromatic and contains many small seeds. The chemical content was given by USDA (2012) in Table 78.

Harvesting and handling

Commercial harvesting should be at colour break to reduce susceptibility to mechanical injury during handling (O'Hare 1993). Fruits harvested 10 or 11

weeks after fruit set could be stored for about 2 weeks at 5 or 10 °C before disease began to develop, but conversely fruits harvested 12 or 13 weeks after fruit set could be successfully stored for 4 weeks at 5 or 10 °C (Osman and Mustaffa 1996). Fruit development in Florida takes 60–70 days to reach harvest maturity. Fruits harvested too early tend to brown severely during storage (Campbell 1989). Harvesting is carried out entirely by hand to reduce physical damage to the fruits (Osman and Mustaffa 1996).

Miller and McDonald (2000) found that cooling the fruits with iced water greatly reduced fruit quality compared with ambient air, ambient water and refrigerated air treatments. Refrigerated air treatment at the targeted storage temperature of 10 °C resulted in the least fruit damage. Refrigerated air, ambient air and ambient water treatments resulted in similar degradation including peel pitting, bronzing, decay and weight loss. However, ambient air fruits were the least firm and ambient water fruits had the lowest flavour quality. Carambolas cooled with refrigerated air had the least injury compared with fruits cooled with the other methods.

1-MCP

Generally, submerging the cultivar Arkin in an aqueous 1-MCP solution at 200 µg L⁻¹ a.i. suppressed total volatile production at both 1/4 and 1/2 yellow harvest maturities or when stored at 5 °C for 14 days and transferred to 20 °C or stored constantly at 20 °C until reaching 1/4 orange stage. 1-MCP suppressed volatile production for fruit stored at 20 °C where the fruit were harvested at the 1/4 and 1/2 yellow stages and total volatiles were suppressed by 14 and 28%, respectively. Treatment with 1-MCP delayed the time to the 1/4 orange stage by 2–5 days at 20 °C (Warren *et al.* 2009).

Postharvest physiology

From experiments, O'Hare (1993) showed that they appeared to be non-climacteric fruits with an ethylene production rate of less than 3 µl C₂H₄ kg⁻¹ h⁻¹ at 20 °C depending on maturity. Exposure to ethylene at 100 µl L⁻¹ for 24 h slightly hastened degreening but had little effect on flavour. Higher rates of ethylene production have been recorded after 12 days at 20 °C

Table 79 Respiration rate carambola fruit
(source: adapted from Shiesh *et al.* 1987)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
5	10–19
10	15–29
15	19–34
20	37–92

but may be associated with decay (Shiesh *et al.* 1987) (Table 79).

Storage

Sugar levels remained constant during storage, although fruits will continue to lose chlorophyll and synthesize carotenoids after harvest. Acidity can decline during storage, and this is often undesirable as it can be associated with a bland flavour. No storage decay was detected in ripe and unripe fruits held at 5 °C for 12 weeks (Wan and Lam 1984). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be 4–5 days and lower humidity resulted in more severe rib edge browning (Mercantilia 1989). Chilling injury symptoms appeared after 5 weeks' storage at 5 °C on unripe fruit but not in ripe fruits (Wan and Lam 1984). Refrigerated storage recommendations include

- 5 °C for 3 weeks with browning, including stem-end browning, being the main limiting factor in storage (Campbell 1989);
- 6 °C and 90% r.h. for 3 weeks (Mercantilia 1989);
- 10 °C for the fresh market fruits and 5 °C for processing (Sankat and Balkissoon 1990);
- 5–10 °C and 90% r.h. for 3–4 weeks (Snowdon 1990);
- 8.9 °C and 85–90% r.h. for 21–28 days (SeaLand 1991);
- 5 °C for 6 weeks (O'Hare 1993);
- 10 °C and 85–88% r.h. (Osman and Mustaffa 1996);
- 4–5 °C and 90–95% r.h. for 21–35 days depending on ripeness (Kader 1999).

Controlled atmosphere storage

Storage at 7 °C and 85–95% r.h. with either 2.2% O₂ and 8.2% CO₂ or 4.2% O₂ and 8% CO₂ resulted in

low losses of about 1.2% in 1 month and fruit retained a bright yellow colour. Controlled atmosphere-stored fruit also had good retention of firmness, °Brix and acidity compared to fruits stored in air (Renel and Thompson 1994).

Modified atmosphere packaging

Unripe fruits stored in sealed 0.04-mm-thick PE bags remained green during storage at 5 °C but turned yellow after the bags were opened and the fruit exposed to 20 °C for 9 days (Wan and Lam 1984). The fruit sealed in PE film bags had a similar flavour after ripened to those stored not wrapped after 1 week at 20 °C for both green and fully coloured fruit. The equilibrium gas content inside the bags was 2.5–4.5% CO₂ and about 15% O₂.

Disorders

The major problem is physical injury, especially on the rib edges, which leads to browning. Injury due to abrasion and impact can be avoided by careful handling. Browning due to mechanical injury can intensify with water loss. Fruit that have lost about 5% of their weight due to water loss show visible symptoms of dehydration.

Diseases

Diseases mainly occur at sites of physical injury and develop during prolonged storage. Anthracnose (*Colletotrichum gloeosporioides*) is most common disease and the symptoms are thin, light brown patches on fruit edges (Watson *et al.* 1988). Diseases due to infection with *Alternaria alternata*, *Cladosporium cladosporioides* and *Botryodiplodia theobroma* have also been reported.

Pests

They require quarantine treatment for control of the Caribbean fruit fly (*Anastrepha suspensa*) prior to shipment to United States and some other countries. Low-dose irradiation (1 kGy) was shown to be effective for protecting against fruit flies, but carambolas are susceptible to irradiation-induced peel injury. In experiments, low-dose γ-irradiation treatment generally reduced fruit quality, but packaging fruit

in clamshell polystyrene containers rather than conventional fibreboard boxes, prior to treatment, mitigated the effects on quality. Use of clamshell containers reduced peel pitting, stem-end breakdown, shrivelling and weight loss after storage at 5 or 7°C for 14 days. Fruits held in clamshell containers were also firmer, with slightly less green peel and had lower total soluble solids contents than fruits stored in fibreboard boxes, but their flavour was not quite as good (Miller and McDonald 1998). Miller and McDonald (2000) recommended hot water and vapour heat treatments for fruit fly control.

Carissa

Apocynaceae

Carissa macrocarpa A. DC. also called Natal Plum. It is a small tree, native of South Africa, which can grow up to about 4 or 5 m high with thick glossy leaves and sharp branched thorns on the branches. The white flowers are fragrant and 5 cm long. The reddish fruit are ovoid or ellipsoid and up to 5 cm long. It is commonly used to make jelly or a sauce similar to cranberry sauce. The chemical content of the fruit was given by USDA (2012) in Table 80.

Cashew apples

Anacardiaceae

Anacardium occidentale L. There are about eight species of *Anacardium*, all of which are tropical trees or shrubs. The cashew tree is a native of tropical America from Mexico to Peru and Brazil and the Caribbean islands and was widely distributed

throughout the tropics by early Spanish and Portuguese explorers. In the 16th century it was taken to India and probably East Africa and Malaysia about the same time (Purseglove 1975). India and, to a lesser extent, East Africa became the largest producers of cashew nuts. The main product of the *A. occidentale* tree is the nut that produces the edible kernel, the cashew nut. The corrosive, but highly useful, cashew nut shell oil is also extracted from the shell of the nut. The apple can be eaten fresh but many varieties are astringent. It makes an excellent juice and is also candied, made into jam and fermented into wine. *A. occidentale* is a spreading evergreen tree up to 12 m high. The portion of the fruit, which is called the apple, is actually the pedicel or swollen fruit stalk. The nut on the end of the pedicel is actually the true fruit. It is hardy and drought resistant and is often grown on hillsides that are too stoney or too dry for other crops. Planting the tree can also act to resist soil erosion.

Filgueiras *et al.* (2002) gave the following chemical components of cashew apple: 84.5–90.4% water, 9.8–14% TSS, 7.7–13.2% total sugars, 0.22–0.52% TA (as malic acid), 130–387 mg 100 g⁻¹ vitamin C and 0.27–0.72% tannins. Anthocyanins levels in stage 7 fruit of the cultivar CCP-76 were 21.5 mg 100 g⁻¹ and total carotenoids were 32 mg 100 g⁻¹. Total world production of cashew apple in 2010 was estimated by FAO (2013) as 1,899,205 tonnes. It is of interest to note that the total world production of cashew nuts, with shells, in 2010 was estimated by FAO (2013) as 2,757,598 tonnes, which illustrates the fact that much of the cashew apple crop goes to waste.

Harvesting and handling

Filgueiras *et al.* (2002) described seven ripening stages of cashew apples where one is dark green (apple and nut) and small and seven is fully developed and fully coloured red or yellow with the fruit becoming softer as they developed. Harvest maturity is usually when they are fully grown and fully coloured. Cashew apples have a very short postharvest life at tropical ambient conditions and may be unsaleable within a day or so of harvesting. They are soft with a thin skin and need handling very delicately. They should be harvested and packed directly in shallow trays and allowed good air circulation to prevent them overheating and then taken to a cool shady place as quickly as possible.

Table 80 The composition of carissa fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	84.17 g	Potassium	260 mg
Energy	62 kcal	Sodium	3 mg
Protein	0.50 g	Total ascorbic acid	38.0 mg
Total lipid (fat)	1.30 g	Thiamine	0.040 mg
Carbohydrate,	13.63 g	Riboflavin	0.060 mg
by difference			
Calcium	11 mg	Niacin	0.200 mg
Iron	1.31 mg	Vitamin B-12	0.00 µg
Magnesium	16 mg	Vitamin A	2 µg RAE
Phosphorus	7 mg	Vitamin A	40 IU

Postharvest physiology

Biale and Barcus (1970) classified the cashew apple as non-climacteric. Pratt and Mendoza (1980) also showed that the pattern of ethylene production confirmed that the cashew apple was non-climacteric. This is predictable since the apple is a pedicel and not a true fruit. The cashew apple grows very slowly until the nut matures (Figure 86), it then grows very rapidly and changes colour from green to red, yellow or orange and softens (Thompson 1968). Removal of the nut from the receptacle initiated rapid growth of the cashew apple and earlier maturation. Filgueiras *et al.* (2002) showed a constant increase in anthocyanins, total carotenoids, TSS, TSS:TA, reducing sugars, vitamin C and tannins as they developed on the tree. Pratt and Mendoza (1980) gave its respiration rate at 20 °C as 50 ml kg⁻¹ h⁻¹ and ethylene production as 200–400 nl kg⁻¹ h⁻¹.

Prestorage treatments

The lowest incidence of microbial decay and weight loss occurred in cashew apples treated with 1% mustard oil, in which the storage limit was 6 days (i.e. some fruits were still not rotten), compared with only 2 days for those that had been dipped in distilled water. In all treatments, fruit TSS content peaked after about 2 days of storage and then declined, and ascorbic acid content decreased throughout storage (Narayan and Ghosh 1993).



Figure 86 Cashew fruit showing the progression of their development with the nut (the true fruit) developing earlier than the fruit stalk (the pedicel). See colour plate section.

Storage

Refrigerated storage recommendations include

- 0–1.7 °C and 85–90% r.h. for 5 weeks with 22% loss (Pantastico 1975);
- 0 °C and 85–90% r.h. for up to 35 days (SeaLand 1991);
- 5 °C and 85–90% r.h. for 15–20 days (Filgueiras *et al.* 2002).

Narayan and Ghosh (1993) successfully stored the cultivar VTH-30 in perforated white PE bags at room temperature of about 28 °C and 66–75% r.h. Filgueiras *et al.* (2002) also recommended MA packaging and Morais *et al.* (2008) using PVC film on four cultivars in Brazil found that in storage at 5 °C and 85–90% r.h. their postharvest life varied between cultivars but was between 10 and 25 days (Yahia 2011a).

Cherimoyas

Annonaceae

Annona cherimola Mill. They originated in the mountain valleys of Peru and Ecuador and were later introduced to Central America. The trees that can be up to 6 m high. The fruit consists of berries fused to a fleshy receptacle, which are heart shaped or conical. The skin is light green in colour and may be covered with shallow depressions marking the outlines of the berries, or each berry may end in an abrupt point. The fruits are large and can be up to 15 cm in diameter and weigh up to 2 kg. The flesh is creamy white with a texture of custard when fully mature and contains many dark brown seeds. Idstein *et al.* (1984) identified that 208 volatile compounds, including 23 hydrocarbons, 58 esters, 54 alcohols, 47 carbonyls and 26 volatiles of miscellaneous structures, were found. Quantitatively, alcohols such as 1-butanol, 3-methyl-1-butanol, 1-hexanol and linalool and a series of butanoates and 3-methylbutyl esters comprised the major part of the volatiles. The chemical content was given by USDA (2012) in Table 81.

Harvesting

This is done by hand when the fruit begin to soften and give out a characteristic odour. There is a change in the greenness of the skin as they mature, but this is subtle and often difficult to assess.

Table 81 The composition of cherimoya fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	79.39 g	Zinc	0.16 mg
Energy	75 kcal	Total ascorbic acid	12.6 mg
Protein	1.57 g	Thiamine	0.101 mg
Total lipid (fat)	0.68 g	Riboflavin	0.131 mg
Carbohydrate, by difference	17.71 g	Niacin	0.644 mg
Total dietary fibre	3.0 g	Vitamin B-6	0.257 mg
Total sugars	12.87 g	Folate	23 µg DFE
Calcium	10 mg	Vitamin B-12	0.00 µg
Iron	0.27 mg	Vitamin A	0 µg RAE
Magnesium	17 mg	Vitamin A	5 IU
Phosphorus	26 mg	Vitamin E	0.27 mg
		(α-tocopherol)	
Potassium	287 mg	Fatty acids, total saturated	0.233 g
		Fatty acids, total monounsaturated	0.055 g
Sodium	7 mg	Fatty acids, total polyunsaturated	0.188 g

Table 82 Respiration rate cherimoya fruit at different temperatures (source: adapted from Palma *et al.* 1993)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
10	47–190
15	84–280
20	138–460

Postharvest physiology

It is classified as a climacteric fruit and displayed a typical climacteric pattern of ethylene production (Li *et al.* 2009). The climacteric rise in respiration rate was delayed by storage in 15 or 10% O₂ and fruits kept in 5% O₂ did not show a detectable climacteric rise and did not produce ethylene. At 20 °C they had high rates of ethylene production of 100–300 µ kg⁻¹ h⁻¹ (Palma *et al.* 1993). Exposure of fruit to ethylene at 100 µl L⁻¹ for 24 h led to rapid ripening of mature green fruit and their respiration rate was given in Table 82. Cordeiro *et al.* (2013) harvested fruit at the mature green stage of the cultivar Madeira and noted that the changes during ripening were chlorophyll degradation, an accentuated decrease of starch and an increase in total free sugars, with glucose the predominant sugar in the mesocarp. They attributed softening mainly to depolymerization of pectin and lipid deterioration rather than hemicellulose degradation.

Storage

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be 3–4 days (Mercantilia 1989). Li *et al.* (2009) found that fruit stored at 20 °C softened within 5 days but fruit exposed to 1-MCP showed delayed softening. They suffered from chilling injury, especially below 10 °C, which results in the skin darkening, failure to soften and a poor mealy flavour (Palma *et al.* 1993), but ripe, soft fruit can be stored at 0–5 °C (Kader and Arpaia 1999). Refrigerated storage recommendations include

- 12 °C and 90% r.h. for 2–3 weeks (Mercantilia 1989);
- 8–9 °C and 90% r.h. for 1–2 weeks (Snowdon 1990);
- 12.8 °C and 90–95% r.h. for 14–28 days (SeaLand 1991);
- 10–13 °C and 90–95% r.h. for 2–3 weeks (Kader and Arpaia 1999).

Controlled atmosphere storage

Fruits of the cultivar Fino de Jete were stored at 9 °C in air, 3% O₂ + 0% CO₂, 3% O₂ + 3% CO₂ or 3% O₂ + 6% CO₂. Low O₂ resulted in the greatest reductions in respiration rate, sugars content and acidity, whereas high CO₂ resulted in the greatest reductions in ethylene production and softening rate. CO₂ at 3 and 6% delayed the softening by 5 and 14 days, respectively, beyond 3% O₂ with 0% CO₂ and air storage. This allowed sufficient accumulation of sugars and acids to reach an acceptable quality. The results suggest that 3% O₂ + 3% CO₂ and 3% O₂ + 6% CO₂ atmospheres can extend their storage life by 2 weeks longer than those stored in air (Alique and Oliveira 1994). The cultivar Concha Lisa was harvested in Chile 240 days after pollination. Respiration rates during storage at 10 °C in air showed a typical climacteric pattern with a peak after some 15 days. The climacteric was delayed by storage in 15 or 10% O₂ and fruits kept in 5% O₂ did not show a detectable climacteric rise and did not produce ethylene. All fruits ripened normally after being transferred to air storage at 20 °C. However, the time needed to reach an edible condition was affected by O₂ level with 11 days in 5% O₂, 6 days in 10% O₂ and 3 days in 20% O₂ (Palma *et al.* 1993). Berger *et al.* (1993) showed that waxed

[unspecified] fruit of the cultivar Bronceada could be stored at 10 °C with 90% r.h. in 0% CO₂ + 5% O₂ for 3 weeks without visible change. Fruits of Fino de Jete were stored for 4 weeks at 10–12 °C in chambers supplied with a continuous flow of CO₂. The CO₂ treatment prolonged the storage life of cherimoyas by at least 3 weeks compared to those stored in air (Martinez Cayuela *et al.* 1986). Escribano *et al.* (1997) found that pre-treatment of the cultivar Fino de Jete for 3 days at 6 °C in 20% CO₂ + 20% O₂ maintained fruit firmness, colour compared to those not treated. They also reported that there were some interactions between cultivar and controlled atmosphere storage treatment. Not all reports on controlled atmosphere storage have been positive. De la Plaza (1980) and Moreno and De la Plaza (1983) showed that fruits of the cultivars Fino de Jete and Campa stored in 10% CO₂ + 2% O₂ had a higher respiration rate than fruits stored at the same temperature in air. Other storage recommendations include

- 8 °C in 10% CO₂ + 2% O₂ (Hatton and Spalding 1990);
- 10 °C, with a range 8–15 °C, in 5% CO₂ + 2–5% O₂ (Kader 1993);
- 8.5 °C and 90% r.h. in 10% CO₂ + 2% O₂ for 22 days (De la Plaza *et al.* 1979).

Modified atmosphere packaging

Melo *et al.* (2002) found that the cultivar Fino de Jete stored at 12 ± 1 °C and 90–95% r.h. had a marketable life in air of 2 weeks, while the fruits packed with zeolite film could be stored for 4 weeks.

Diseases

The major postharvest diseases were reported to be from preharvest infections and could be controlled by good field sanitation, prompt precooling and perhaps fungicide treatment. Diseases include Anthracnose (*Colletotrichum gloeosporioides*) that appears as dark lesions and may produce pink spore masses under high humidity. Black canker (*Phomopsis anonacearum*) appears as purple spots that becomes hard and cracked while Botryodiplodia rot (*Botryodiplodia theobroma*) first appears as purple, later black spots and the flesh becomes brown and corky (Snowdon 1990).

Cherry

Rosaceae

Prunus avium L., also called sweet cherry. The modern cultivars were selected from the Mazzard or Gean, which is a tall tree that probably originated in Asia Minor. The Mazzard has small dark red to black fruits that have a rich flavour. Modern cultivars are the same colour but can also be yellow with a red flush. It is a large temperate tree that produces fruit that are drupes and consist of the outer layers of the mature ovary wall, the flesh (mesocarp) and the skin (exocarp) with the pit (endocarp) enclosing the seed. The fruit will freeze at about –4.3 to –3.8 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 83. Total world production in 2010 was estimated by FAO (2013) as 2,064,421 tonnes.

Harvesting and handling

Harvest maturity is when the skin turns a bright red colour, delaying harvest until the skin turns a dark red results in them having a better flavour but a shorter marketable life. Also the red colour makes them attractive to birds and the longer they are left before harvesting the greater will be the loss. Czabaffy (1984,

Table 83 The composition of sweet cherry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	82.25 g	Thiamine	0.027 mg
Energy	63 kcal	Riboflavin	0.033 mg
Protein	1.06 g	Niacin	0.154 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.049 mg
Carbohydrate, by difference	16.01 g	Folate	4 µg DFE
Total dietary fibre	2.1 g	Vitamin B-12	0.00 µg
Total sugars	12.82 g	Vitamin D (D2 + D3)	3 µg RAE
Calcium	13 mg	Vitamin A	64 IU
Iron	0.36 mg	Vitamin E (α-tocopherol)	0.07 mg
Magnesium	11 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	21 mg	Vitamin D	0 IU
Potassium	222 mg	Vitamin K (phylloquinone)	2.1 µg
Sodium	0 mg	Fatty acids, total saturated	0.038 g
Zinc	0.07 mg	Fatty acids, total monounsaturated	0.047 g
Total ascorbic acid	7.0 mg	Fatty acids, total polyunsaturated	0.052 g

1985) measured diffuse light transmission in the range 380–730 nm through cherries and found that it was shown to be affected by the level of chlorophyll in the fruit. Chlorophyll decreases during maturation so this could be used as a maturity measurement.

They are harvested by hand with the pedicel still attached. This can be done by twisting the end of the pedicel where it attaches to the branch but in many cases they can be detached by simply drawing the finger across the branch so that several groups of fruit are harvested at the same time. Where fruit parts from the pedicel as it joins the fruit these would normally be rejected from commercial harvests since such fruit are referred to as being plugged and juice may be leaked and they may have a shorter postharvest life. The trees can be tall and therefore pickers often use ladders or mechanical platforms. These latter gave rise to the name 'cherry picker' for the platforms used to service street lighting and pruning trees (Figure 13).

Air cooling in a conventional cold store was the most suitable method, forced air cooling with high humidity was also suitable, hydrocooling was less suitable and vacuum cooling was generally considered unsuitable (MAFF n.d.). Stow *et al.* (2004) recommended cooling to 1 °C within 36 h to maximize their postharvest life.

Postharvest physiology

The fruit is classified as non-climacteric. Sweet cherries produce very low amounts of ethylene but will respond to exogenous or wound-induced ethylene with increased respiration and quality loss (Mattheis and Fellman 2002) (Table 84).

Storage

Refrigerated storage recommendations include

- –1 to 0 °C and 85–90% r.h. for 1–4 weeks (Anonymous, 1967);
- 0 °C and 90–95% r.h. for 14 days (Mercantilia 1989);
- 4 °C for 9 days (Mercantilia 1989);
- 10 °C for 5 days (Mercantilia 1989);
- 20 °C for 2 days (Mercantilia 1989);
- –1 to 0 °C with greater than 95% r.h. for 2–4 weeks (Kader 1989);

Table 84 Respiration rate sweet cherry fruit at different temperatures (source: adapted from Mattheis and Fellman 2002)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	6–10
5	16–28
10	20–36
15	28–64
20	40–90

- –1 to –0.6 °C and 90–95% r.h. (Hardenburg *et al.* 1990);
- –1 to 0 °C and 90–95% r.h. for 2–3 weeks (Snowdon 1990);
- –1.1 °C and 90–95% r.h. for 14–21 days (SeaLand 1991).

Controlled atmosphere storage

CA storage recommendations include

- –1 to –0.6 °C with 20–25% CO₂ and 0.5–2% O₂ helped to retain fruit firmness, green pedicels and bright fruit colour (Hardenburg *et al.* 1990);
- –1.1 with 20–25% CO₂ with 10–20% O₂ (SeaLand 1991);
- 20–30% CO₂ reduced decay (Haard and Salunkhe 1975);
- 0–5 °C with 10–12% CO₂ and 3–10% O₂ (Kader 1985, 1989);
- 0–5 °C with 5–10% O₂ + 5–15% CO₂ (Mattheis and Fellman 2002);
- 1 °C and 95% r.h. in 2% CO₂ + 5% O₂ for sweet-heart for up to 6 weeks retained their anthocyanin content and the polyphenol oxidase activity was at its lowest (Remón *et al.* 2003);
- 1 °C + 95% r.h. in 10% CO₂ + 2% O₂ 21 days plus 2 days at 20 °C to simulate shelf life (Luchsinger *et al.* 2005);
- 0 ± 0.5 °C in 20 or 25% CO₂ + 5% O₂ for the cultivar 0900 Ziraat for up to 60 days (Akbulak *et al.* 2008).

Stow *et al.* (2004) found that there were no consistent effects of the 16 combinations of 0, 5, 10 and 20% CO₂ with 1, 2, 4 and 21% O₂, respectively, and, overall, CA storage was not superior to air storage for the cultivars Stella, German Late, Colney, Pointed

Black and Lapins. It was concluded that the maximum storage life could be obtained if the fruit had been cooled to 1 °C within 36 h of harvest and thereafter maintained at 0 °C in air. Rotting was the major cause of loss during storage at 0 °C and especially during subsequent shelf life at 10 or 20 °C. Shellie *et al.* (2001) had previously shown similar results in experiments with the cultivar Bing stored for 14 days at 1 °C in 6% O₂ + 17% CO₂ + 82% N₂. They had similar market quality as cherries stored in air. In spite of these findings there is considerable evidence that both CA and MA storage can be beneficial. In a comparison between of 4 and 20% O₂ + 5 or 12% CO₂ the best results for up to 12 days for the cultivar Burlat were 12% CO₂ atmospheres, independently of O₂ concentration. In these conditions there was a higher acidity level and lower anthocyanin content, lower levels of peroxidase and polyphenoloxidase activities (Remón *et al.* 2004). The cultivars Star, Kordia and Regina were stored at 1 °C with 90–93% r.h. for up to 3 weeks in 10% CO₂ + 10% O₂, 15% CO₂ + 10% O₂ or 20% CO₂ + 10% O₂ followed by storage in air for 1 week at 20 °C with 60% r.h. CA storage decreased their respiration rate, compared with air and improved stem colour retention and condition, but there was little difference between CA and air storage on sugar and acid levels (Gasser *et al.* 2004). Lapis stored in 5% O₂ + 10% CO₂ were firmer and had higher vitamin C and TA than those in MA packaging or CA with higher O₂ levels but soluble solids contents were not significantly affected by CA (Tian *et al.* 2004).

Storage at 1 °C with 5% O₂ + 10% CO₂ inhibited the enzymatic activities of polyphenol oxidase and peroxidase, reduced malondialdehyde content, effectively prevented flesh browning, decreased fruit decay and extended storage life more than those stored in air, MA or 70% O₂ + 0% CO₂. Storage in 70% O₂ + 0% CO₂ was more effective at inhibiting ethanol production in flesh and reducing decay than other treatments but showed increased fruit browning after 40 days of storage. Sweetheart cherries were stored for 6 weeks at 1 °C and 95% r.h. with 2% CO₂ + 5% O₂ while maintaining an excellent quality throughout their storage and shelf life of 3 days at 20 °C. Under these conditions they had the highest acceptability and appearance score, anthocyanin content remained unchanged and polyphenoloxidase activity was at its lowest level (Remón *et al.* 2003). Tian *et al.* (2004) also reported that storage of the cultivar Lapis at 1 °C

in 70% O₂ + 0% CO₂ was effective in reducing decay but stimulated fruit browning after 40 days. Storage in 2% O₂ + 5% CO₂, 5% O₂ + 10% CO₂ and 5% O₂ + 15% CO₂, with N₂ the balance, inhibited grey mould (*Botrytis cinerea*) development after 18 days at 1 °C plus 6 days at ambient (Wermund and Lazar 2003).

Modified atmosphere packaging

Bing cherries were successfully stored for 2 months at 0 °C in Xtend, a plastic film which results in high internal CO₂ atmospheres. The gas concentration stabilized within 4 days and remained at 7.5% CO₂ and 16% O₂ for 2 months. The main benefit of the Xtend film on cherry quality was reduction of weight loss and maintenance of green pedicel on the fruit. Chinook cherries were also stored successfully for a shorter period of time. Comparison of polyethylene film and Xtend in Chinook cherries showed that green pedicels were maintained better in the Xtend film than in polyethylene bags (Lurie *et al.* 1997).

Hypobaric storage

Hypobaric treatments prolonged the storage life of cherries by 16–33 days. They delayed chlorophyll and starch breakdown, carotenoid formation and the decrease in sugars and TA (Salunkhe and Wu 1973). The effectiveness of short hypobaric treatments against postharvest rots was investigated by Romanazzi *et al.* (2001). Ferrovia sweet cherries exposed to 0.50 atm. for 4 h had the lowest incidence *Botrytis cinerea*, *Monilinia laxa* and total rots.

Diseases

A range of fungi have been reported to infect cherry fruits including *Alternaria alternata*, *Botryotinia fuckeliana*, *Botrytis cinerea*, *Cladosporium herbarum*, *Colletotrichum gloeosporioides*, *Monilina* spp., *Penicillium expansum*, *Rhizopus* spp. and *Stigmata carpophila* (Snowdon 1990). In an experiment, fruit of the cultivar Hedelfingen were inoculated with spores of *Botrytis cinerea*. They were then fumigated with 30 mg L⁻¹ of thymol or acetic acid, for 25 min before sealing in modified atmosphere packages and storage at 0 °C. After 10 weeks of storage, thymol or acetic acid reduced grey mould rot of *B. cinerea*

inoculated cherries from 36 to 0.5 or 6%, respectively. However, fruit fumigated with thymol had lower total soluble solids, higher TA and greater stem browning than acetic acid or non-treated cherries (Chu *et al.* 1999). Xu and Tian (2008) found that 2 mM salicylic acid did not inhibit *Penicillium expansum* growth *in vitro* but it activated antioxidant defence responses of fruit of the sweet cherry cultivar Hongdeng, which may play a role in the resistance against *P. expansum*. However, Yao and Tian (2005) found that 2 mM salicylic acid showed direct fungitoxicity on *Monilinia fructicola* and significantly inhibited mycelial growth and spore germination of the pathogen *in vitro*.

Physiological disorders

Scald is a localized translocation of the red pigments and is related to bruising (Hulme 1971). Cracking is a physiological disorder that can occur to fruit on the tree, which often serves as entry points for decay organisms. The cracking in cherries occurs when it absorbs water; some varieties are more susceptible than others. The speed of water intake, skin permeability, fruit turgor and soil type can affect the incidence of cracking (Simon 2006). Yildirim and Koyuncu (2010) sprayed cherry trees with 20 ppm GA₃ when the fruits were at the straw-yellow stage, which was about 30–40 days prior to the harvest. They found that GA₃ treatments decreased the fruit cracking rate by 77.8% as well as delaying the harvest date by 3–4 days and increased the fruit weight by 10.71% in comparison with those that had not been sprayed. The fruit that had been sprayed with GA₃ were brighter and darker red than those that had not been sprayed. Hulme (1971) reported that cracking could occur when fruits are held at high temperature after harvest and rapid cooling after harvest could be used as a control cracking.

Chinese jujube

Rhamnaceae

Zizyphus jujuba Mill. It originated and has been cultivated in China for at least 4000 years (Purseglove 1968). This is a deciduous tree of temperate regions. The fruit is a drupe and its pulp has a crisp texture with a sweetish sub-acid flavour. See also the Indian jujube, *Z. mauritiana*. The chemical content was given by USDA (2012) in Table 85.

Table 85 The composition of Chinese jujube fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	77.86 g	Sodium	3 mg
Energy	79 kcal	Zinc	0.05 mg
Protein	1.20 g	Total ascorbic acid	69.0 mg
Total lipid (fat)	0.20 g	Thiamine	0.020 mg
Carbohydrate, by difference	20.23 g	Riboflavin	0.040 mg
Calcium	21 mg	Niacin	0.900 mg
Iron	0.48 mg	Vitamin B-6	0.081 mg
Magnesium	10 mg	Vitamin B-12	0.00 µg
Phosphorus	23 mg	Vitamin A	2 µg RAE
Potassium	250 mg	Vitamin A	40 IU

Harvesting

They are harvested from the tree by hand usually when the skin has turned an orange-red colour with just a hint of brown and they are still firm.

Prestorage treatment

Wu *et al.* (2001) showed that treatment with 1% calcium chloride or 1% calcium chloride + 15 mg 6-benzyladenine per litre reduced the rate of ascorbic acid loss and the decrease in flesh firmness and loss in fresh fruit. The effect of 15 mg 6-benzyladenine per litre on respiration rate and fruit quality was lower than that of the calcium chloride treatment.

Storage

They will ripen and become soft and sweet with a brown skin after 1–2 days at room temperature. Wu *et al.* (2001) stored the cultivars Zanhuan Dazao and Shenglizao, at 0 °C, which resulted in an initial accumulation of ascorbic acid, followed by a gradual decrease and the flesh firmness also gradually decreased.

Diseases

Cao *et al.* (2012a, 2012b) reported that potassium tetraborate was effective in controlling blue mould caused by *Penicillium expansum* in jujube fruit. They also found that 5% boron enhanced the biocontrol efficacy of the antagonistic yeast *Cryptococcus laurentii* against *P. expansum* and they suggested that this enhancement may be related to the differential influence of boron on *C. laurentii* and

P. expansum. Zhu *et al.* (2010) evaluated the effects of postharvest treatment with brassinosteroids against *P. expansum* and on fruit senescence. They found that 5 μ M brassinosteroids effectively inhibited the development of blue mould rot and enhanced the activities of defence-related enzymes, such as phenylalanine ammonia-lyase, polyphenoloxidase, catalase and superoxide dismutase and delayed fruit senescence by reducing ethylene production.

Chinese squash

Cucurbitaceae

Benincasa hispida (Thunb.) Cogn., also called Fuzzy Melon. It occurs wild on the island of Java in Indonesia and has been introduced throughout tropical Asia. It is a robust climbing annual monoecious herb with cylindrical to long oblong fruit that are up to 35 cm long and 20 cm wide. Immature fruit are green coloured with many bristle-like trichomes. The flesh is white and spongy and contains numerous seeds. Fruits of some varieties may be left to mature to become wax gourds that can be stored for long periods. Purseglove (1975) gave the following composition for the fruit as 96% moisture, 3.2% carbohydrate, 0.4% protein, 0.1% fat and 0.3% minerals.

Zong *et al.* (1993) gave the respiration rate of fruit as 5 at 0 °C, 9 at 5 °C, 12 at 10 °C, 12 at 15 °C and 25 ml CO₂ kg⁻¹ h⁻¹ at 20 °C. They also found that they suffered from chilling injury during storage below 10 °C as pitting, tissue discolouration, watery breakdown and increased decay. They concluded that they should not be stored below 10–12.5 °C. They also found that seed development and colour changes continued during storage at temperatures above 12.5 °C.

Chinese white pear

Rosaecae

Pyrus bertschneideri Rehder or *P. × bertschneideri* Rehder. It is usually considered an interspecific hybrid and recent genetic evidence confirms some relationship to the Siberian pear (*P. ussuriensis*), but it has also been classified as a subspecies of the Chinese pear (*P. pyrifolia*). In 2012 the draft genome of *P. bertschneideri* was reported from Nanjing in China. It is native to northern and north-western

China and is cultivated from central to eastern China, Japan, central Asia and United States. These are very juicy, white to light yellow pears, unlike the round *P. pyrifolia* they are shaped more like a European pear, narrow towards the stem end.

Chen *et al.* (2010) reported that fruits that had been treated with 1-MCP had decreased losses in flesh firmness and TA. 1-MCP treatment also inhibited flesh browning and delayed change in skin colour and reduced polyphenol oxidase activity and accumulation of malondialdehyde during cold storage but 1-MCP had little effect on their TSS and respiration rate. They were also given a higher taste panel score after shelf life. These effects were higher when fruits were vacuum infiltrated with 1-MCP. They found that vacuum infiltration was the most effective method of application.

Cao and Jiang (2006) showed that disease incidence and lesion diameter in mature pears of the cultivar Yali from trees sprayed with acibenzolar-S-methyl for three times during growth and inoculated with *Penicillium expansum* had disease incidence of 27.9% and lesion diameter of 29.1% or inoculated with *Alternaria alternata* the disease incidence was 42.7% and lesion diameter 23.4% than in control fruit 17 days after inoculation. The study indicated that enhancement of disease resistance in harvested Yali pear fruit could be the result of multiple effects of several factors related to plant defences induced by acibenzolar-S-methyl sprays on trees during fruit growth. Wan and Tian (2005) found that there was good control of *Penicillium expansum* and *Alternaria alternata* in pears by treatment with the antagonistic yeast *Rhodotorula glutinis* combined with 1 mmol L⁻¹ ammonium molybdate. They reported that combination of antagonistic yeasts and ammonium molybdate did not effect fruit firmness and TSS. They also reported that ammonium molybdate did not lead to mortality or adverse effects in test animals and was also an environmentally safe and cheap. Lin *et al.* (2008) reported that 1.5% chitosan, alone or combined with 10 mmol L⁻¹ ascorbic acid, coating of fruit was more effective in controlling core browning in the cultivar Yali during storage at room temperature of 25 ± 1 °C. They concluded that this could be due to not only reducing the respiration rate and inhibiting the senescence process but also increasing the antioxidant capability of the fruit.

Citron

Rutaceae

Citrus medica L. It originated in the area of southern China to India and was one of the first citrus fruits to be brought to the Mediterranean area about 300 BCE. It is a small evergreen tree up to about 3 m high. The fruit is a berry or hesperidium and is non-climacteric. It is oblong in shape and up to 20 cm long with a bumpy peel that is usually very thick. The pulp area is small, green and sour (Purseglove 1968). Its main use is for candied peel.

Citrus hybrids

Rutaceae

Most *Citrus* spp. hybridizes easily and a large number of hybrids are cultivated. The ones that produce the most popular fruit are those between mandarin and grapefruit (*C. reticulata* × *C. paradisi* Macf.) and include uglifruit, minneola (mineola), tangelo and orlando (Figure 87) and those between mandarin and oranges (*C. reticulata* Blanco × *C. sinensis* (L.) Osbeck) that include ortanique, murcott, tangor, temple orange and umatilla. There are also hybrids between *C. sinensis* × *C. paradisi* called orangelo.

Ortanique fruit were seen in Jamaica at the Christians market where a man called C.P. Jackson, from Mandeville, bought two of the fruits. From those he planted 130 seeds and selected the least thorny,

least seedy and named the fruit from a contraction of orange, tangerine and unique. The name ortanique is exclusive to those produced in Jamaica and in the 1970s other countries acquired them, including Cuba, and were not permitted to export them as ortaniques and therefore Cuba called them Cubaniques. The Citrus Growers Association of Jamaica took charge of the marketing for export in 1944 (Morton 1987). They are sweet and delicious but have many seeds.

Murcott were first found in the south of the United States in the early part of the 20th century and are also seedy with a semi-hollow central axis. They are also called Honey Murcott and Murcott Honey Orange. The fruit is oblate, of medium size, 7–8 cm wide and about 5 cm high with yellow to deep-orange, glossy, smooth, faintly ribbed, thin peel that clings to the pulp but is easily removed when fresh. Because of the thin peel, the fruit is clipped from the tree, not pulled because it might tear the peel. It stores well (Morton 1987).

Temple orange was found in Jamaica in the late 19th century, but it is now grown throughout the tropics and sub-tropics. They are easier to peel than oranges but more difficult than tangerines and are usually very seedy. The fruit is oblate to round, medium to large, 6.6–8.25 cm wide and 5.7–6.25 cm high with deep-orange to red-orange, glossy, slightly rough, loose, thick, leathery peel. The pulp is orange and melting and has a rich flavour. Each medium-sized fruit contains about 20 seeds (Morton 1987).

Umatilla fruit are oblate to rounded up to 12 cm wide and 7 cm high with red-orange, smooth, glossy, medium-thick, not very loose peel and orange pulp. They are melting and very juicy with a rich sweet acid flavour with 10 or more large seeds or occasionally none (Morton 1987).

Uglifruit was selected about 1917 by G.G.R. Sharp, who owned Trout Hall Estate in Jamaica and began exporting them to Britain and Canada in 1934 and subsequently to the United States. The fruit is obovate, compressed to nearly oblate, necked at the base, and puffy. They are 10–15 cm wide and 8–12 cm high. The peel is light-yellow with light-green areas at the apex, leathery, loose, medium-thin peel. The albedo is thick, the pulp is light-orange in colour divided into 12 segments with tough membranes. It is easy to peel, tender, melting, very juicy, with a fine flavour, seedless or with few seeds.



Figure 87 Minneola is a hybrid between a Duncan grapefruit and a Dancy tangerine. See colour plate section.

Minneola is oblate, faintly necked about 8 cm wide and 8 cm high, deep red-orange peel, thin, firm, tight orange peel, melting, sweet acid; of fine flavour with up to 12 seeds (Figure 87).

Orlando is oblate to rounded, 8 cm wide and 7 cm high. The peel is deep-orange, slightly rough and tight. The pulp is deep-orange, with 12–14 segments, melting, very juicy, sweet with up to 12 seeds.

Citrus spp. can also hybridize with other genera of Rutaceae including *Fortunella* spp. and trifoliolate orange (*Poncirus trifoliata*). These include citrange a hybrid between the orange and trifoliolate orange, limequat a hybrid between the marumi kumquat and West Indian lime, Eustis limequat a hybrid between Mexican lime and marumi kumquat or limequat, Lemonquat a hybrid between lemon and the kumquat, Nippon orangequat (*C. reticulata satsuma* × *Fortunella margarita medua*), Procimequat (*C. aurantifolia* × *Fortunella japonica* × *Fortunella hindsii*), Sinton (Citrangquat) a hybrid between oval kumquat and rusk citrange, Sydney (*Microcitrus australasica* × *australasica*), Indio mandarinquat a hybrid between kumquat and mandarin with orange and rangpur (*Citrus* × *limonia*) is a lemon and mandarin hybrid that originated in India.

The fruit is a berry or hesperidium, which is non-climacteric. They are hybrids and therefore there are many different types and they have different morphological characteristics even when they are selections from the same type of bispecific cross. Generally they have all been selected for their deep orange coloured peel and flesh and delicious flavour.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 7–10 days. Temple oranges have been shown to be susceptible to chilling injury at 0 °C therefore 3.3 °C was recommended for up to 4 weeks by Lutz and Hardenburg (1968). Other refrigerated storage recommendations include

- 3.3 °C and 85–90% r.h. for 4 weeks for Orlando tangelo (Lutz and Hardenburg 1968);
- 4 °C and 90% r.h. for 3–5 weeks (Mercantilia 1989);
- 4–5 °C and 90% r.h. for 3–5 weeks for ortaniques (Snowdon 1990).

- 4.4 °C and 90–95% r.h. for 14–21 days for uglifruit (SeaLand 1991);
- 3.3 °C and 90–95% r.h. for 21–35 days for minneola (SeaLand 1991).

Disease

Diseases are similar to those of other *Citrus* spp. Storage experiments using various organically grown minneolas showed that hot water brushing at 56 °C for 20 s reduced decay development by 45–55% and did not cause surface damage. Also it did not increase weight loss or internal quality parameters (Porat *et al.* 2000).

Clementines

Rutaceae

Citrus reticulata Blanco. It is thought to have originated in China and to be similar to the Canton Mandarin. Father Clement Rodier in Morocco selected and described it in the late 19th century. The fruit is a berry or hesperidium, which is non-climacteric. According to Davies and Albrigo (1994) the fruit are seedless, with the exception of the variety Monreal. Many different varieties are grown in the Mediterranean region as well as other sub-tropical and tropical climates. The chemical content was given by USDA (2012) in Table 86.

Harvesting

The juice content increased as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit it is possible to specify its maturity. In the United States the minimum juice content at harvest should be 40%.

Degreening

The actual choice of conditions will vary between different situations, particularly whether they have been grown in the tropics or sub-tropics. The cultivar and the stage of maturity at harvest should also be taken into account. Generally the optimum conditions for degreening were a temperature within

Table 86 The composition of clementine fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.58 g	Sodium	1 mg
Energy	47 kcal	Zinc	0.06 mg
Protein	0.85 g	Total ascorbic acid	48.8 mg
Total lipid (fat)	0.15 g	Thiamine	0.086 mg
Carbohydrate, by difference	12.02 g	Riboflavin	0.030 mg
Total dietary fibre	1.7 g	Niacin	0.636 mg
Total sugars	9.18 g	Vitamin B-6	0.075 mg
Calcium	30 mg	Folate	24 µg DFE
Iron	0.14 mg	Vitamin E	0.20 mg
		(α -tocopherol)	
Magnesium	10 mg	Vitamin D	0.0 µg
		(D2 + D3)	
Phosphorus	21 mg	Vitamin D	0 IU
Potassium	177 mg	Vitamin K	0.0 µg
		(phyloquinone)	

the range 25–29 °C, humidity as high as possible, generally between 90 and 95% r.h. and ethylene at between 1 and 10 µL L⁻¹ for 24–72 h. Sdiri *et al.* (2012) found that with the cultivars Clemenules, Clemenpons, Oronules, Prenules, Basol, Clemenrubí and Oro gros clementines exposure to 2000 µL L⁻¹ ethylene for 120 h at 21 °C and 95% r.h. and then 1 °C for 16 days as a quarantine treatment plus 7 days at 20 °C and 95% r.h. for shelf life did not result in detrimental changes in antioxidant capacities, ascorbic acid or total phenolic content. Although some changes were observed in individual flavonoid compounds, these did not contribute to a loss in the total content of flavanones and flavones after ethylene degreening and the subsequent quarantine treatment.

Storage

Refrigerated storage recommendations include

- 0–3 °C and 85–90% r.h. for 1–2 weeks (Mercantilia 1989);
- 4–5 °C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 4.4 °C and 90–95% r.h. for 2–4 weeks (SeaLand 1991).

Diseases

Youssef *et al.* (2012a) reported that most decay was caused by *Penicillium digitatum* and *P. italicum*, with

an average incidence of 11% for Comune Clementines. Decay caused by *Botrytis cinerea* and *Alternaria* spp. was also observed during storage at 6 °C for 1 month followed by 1 week of shelf life at 20 ± 2 °C. Those treated with Imazalil had less than 1% postharvest rots. Youssef *et al.* (2012a, 2012b) reported that aqueous salt solutions applied at 2%, w/v, 20 hl ha⁻¹ by spraying before harvest or dipping after harvest were stored at 6 ± 1 °C and 95–98% r.h., followed by 7 days of shelf life at 20 ± 2 °C. Preharvest application of sodium carbonate and potassium carbonate completely inhibited the incidence of decay as compared to the water control. When salts were applied after harvest, the activity was in general less pronounced with sodium carbonate and potassium carbonate being the most effective. X-ray irradiation (510 Gy) of intact unwounded clemenules mandarins increased the peel biosynthesis of the phytoalexins scoparone and scopoletin after storage at 20 °C for up to 14 days, but not at 5 °C for up to 60 days. Clementines that were wounded, irradiated at 510 Gy and inoculated with *P. digitatum*, contained higher phytoalexin levels than non-irradiated ones. Sodium carbonate (3%) treatment and irradiation at 510 Gy induced highest scoparone and scopoletin accumulation 3 days postfungal inoculation at 20 °C and effectively inhibited green mould, but phytoalexin levels declined and disease control failed 5 days after fungal inoculation (Rojas-Argudo *et al.* 2012).

Pests

Sdiri *et al.* (2012) described exposure to 1 °C for 16 days as a quarantine treatment against the fruit fly *Ceratitis capitata* in the cultivars Clemenules, Clemenpons, Oronules, Prenules, Basol, Clemenrubí and Oro gros clementines.

Cloudberries

Rosaceae

Rubus chamaemorus L. also called baked apple berries. The fruit is a collection of drupes. It produces small golden coloured fruit, similar to blackberries (*R. ulmifolius*) and grows wild in boggy areas in cold northern climates including Arctic Russia and within the Arctic Circle. Because they grow in cold climates the berries are said to mature slowly and develop an intense sweet flavour.

Cocona

Solanum sessiliflorum Dunal, synonymous with *S. alibile* R.E.Schult. *S. arecunarium* Pittier, *S. topiro* Dunal and *S. hyporhodium* A. Br & Bouche. Other common names include maná-cubiu, maná, topiro and tomate de índio. It is native to the Andean region of south America specifically the eastern slopes of the Andes of Peru, Ecuador and Colombia between 200 and 1000 m or to the western Amazon and was domesticated by pre-Columbian Amerindians. It is used for a variety of purposes including food, medical and cosmetics purposes (da Silva *et al.* 2011). It is a subtropical tree but is thought to be adaptable to lower elevations in the humid tropics (Kennard and Winters 1960) in the Amazon region of Brazil. The plant has sturdy branches with large, serrate, hairy leaves growing up to 2 m high. Its flowers resemble potato flowers (*S. tuberosum*) but are large, up to 5 cm in diameter, produced in small axillary racemes, with light green petals. The fruit is a red, orange or yellow edible berry about 4–12 cm wide and 3–6 cm long, weighing between 24 and 250 g (Akimoo Directory n.d.) or 3–10 cm diameter (Purseglove 1975). The skin is soft and surrounds the pulp, thick, yellow and has a flavour has been described as watery or between a lemon and a tomato. Plants can be distinguished from naranjilla (*S. quitoense*) by its lack of spines and having cream coloured pulp (Kennard and Winters 1960). It is low in calories with potassium 54.6–463.5 mg and iron 97.3–352.0 100 g⁻¹ of pulp and they contain high levels of niacin (vitamin B3) (da Silva *et al.* 2011).

Harvesting

The fruits grow rapidly up to 80 days after anthesis when they are yellow and begin changing to orange around 90 days, to deep orange around 100 days and orange-brown, around 110 days after anthesis (da Silva *et al.* 2011). Optimum harvest is when the skin is an even yellow colour.

Postharvest physiology

da Silva *et al.* (2011) reported that they were climacteric, but Akimoo Directory (n.d.) contradicted this and found that they were non-climacteric.

Storage

Fresh fruits keep well for 5–10 days at room temperature. Akimoo Directory (n.d.) reported that storage at 7 °C resulted in the skin turning dark brown by day 7 and from day 9–12, the fruits showed signs of chilling injury, which appeared as brown spots in small depressions. da Silva *et al.* (2011) harvested physiologically mature fruits of the cultivar Mosquet washed them and soaked them in a solution of the fungicide Prochloraz (49.5 g 100 L⁻¹ of water) for 5 min. After air drying, the fruits were packed in plastic containers and stored at 24 ± 2 °C and 60 ± 5% r.h. The fruits remained fit for consumption for up to day 6, which is without visual symptoms of loss of water and firmness with 6.62 °Brix and 1.22% citric acid. Anonymous 3 (n.d.) reported that they could be stored at room temperature with excellent ventilation and shade for up to 5 days. Also they could be stored at 15 °C and 80% r.h. for 19 days, after which time they had symptoms of senescence, dehydration, rapid weight loss and loss of firmness.

Cranberries

Vacciniaceae

Vaccinium L. There are several species of *Vaccinium* that are called cranberry including the American cranberry, *V. macrocarpon* Aiton, which is the most vigorous, and the European or small cranberry, *V. oxycoccus* L. that bears smaller fruit. The American cranberry is native to acid bogs from Newfoundland to North Carolina and west to Minnesota. Cranberry juice was used as a traditional medicine by North American Indians and subsequently by American sailors to ward off scurvy during long voyages. It is a rich source of ascorbic acid and other antioxidants and may have benefits in combating urinary tract and the cardiovascular system. It was probably served at the first thanksgiving feast in America at Cape Cod in 1621. It is a perennial, woody, creeping, evergreen shrub whose fruit is a bright red berry. The chemical content was given by USDA (2011) in Table 87. Total world production in 2010 was estimated by FAO (2013) as 395,040 tonnes.

Harvesting

Harvest maturity is judged on berry size and colour where almost all the fruit should have turned from

Table 87 The composition of cranberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.13 g	Thiamine	0.012 mg
Energy	46 kcal	Riboflavin	0.020 mg
Protein	0.39 g	Niacin	0.101 mg
Total lipid (fat)	0.13 g	Vitamin B-6	0.057 mg
Carbohydrate, by difference	12.20 g	Folate	1 µg DFE
Total dietary fibre	4.6 g	Vitamin B-12	0.00 µg
Total sugars	4.04 g	Vitamin A	3 µg RAE
Calcium	8 mg	Vitamin A	60 IU
Iron	0.25 mg	Vitamin E	1.20 mg
		(α-tocopherol)	
Magnesium	6 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	13 mg	Vitamin D	0 IU
Potassium	85 mg	Vitamin K	5.1 µg
		(phyllloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.011 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.018 g
Total ascorbic acid	13.3 mg	Fatty acids, total polyunsaturated	0.055 g

green to red before harvesting. In North America it is harvested in autumn, but can be left on the plant throughout winter when protected from frost (Hulme 1971). A jump test machine has been developed for measuring the maturity of the fruits postharvest. The berries are bounced and those that are considered just ripe will rebound higher than over and under ripe fruits. In the United States they are grown in swampy areas and the fields flooded in winter to protect them from frost. This can be used to advantage in harvesting mechanically. Scoops are used to aid manual harvesting. They have wooden tines spaced about 1 cm apart. These are combed through the bushes dislodging the berries and depositing them at the back of the scoop. Mechanical harvesters are used mainly for fruits that are to be processed. Many other types of harvester have been developed, some are used on flooded fields and others on dry fields; the latter is better if the fruit are to be marketed fresh but they are usually less efficient. There was more fungal decay and physiological breakdown in water-harvested than hand-harvested cranberries, especially if they are kept in the water more than 1 h after detachment from the plant (Mitcham *et al.* 1999).

Table 88 Respiration rate of cranberry fruit at different temperatures (source: adapted from Kader 1992)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	4
4–5	4–6
10	8
20–21	12–20

Postharvest physiology

They have a low ethylene production rate of 0.1–1.0 µl kg⁻¹ h⁻¹ at 5 °C (Kader 1992), but exposure to ethylene as low as 10 µl L⁻¹ increased anthocyanin content, especially while kept in the light (Craker 1971). Kader (1992) reported their respiration rate in Table 88. Poorly coloured fruit can be improved by holding them at 7.2–10 °C for a few weeks after harvest (Phillips and Armstrong 1967, Lutz and Hardenburg 1968).

Storage

Traditionally much of the crop was reported to be held in common storage in the United States (Anonymous 1968, Lutz and Hardenburg 1968) and Canada (Phillips and Armstrong 1967). At room temperature of 20 °C and 60% r.h. they could be kept for 10–14 days (Mercantilia 1989). They will freeze at about –2.9 to –2.4 °C (Wright 1942). Chilling injury occurred in storage below 2.5 °C as a change in flesh texture from crisp to rubbery and a loss of natural lustre (Fidler 1963). Lutz and Hardenburg (1968) reported that storage for longer than 4–8 weeks at 0 °C may lead to chilling injury and Snowdon (1990) reported that chilling injury could occur after only 2 weeks storage at 0 °C. Levine *et al.* (1941) recommended storing fruit, especially early harvested fruit, at 7–10 °C for a few weeks to improve their red colour. Refrigerated storage recommendations include

- 2.2–3.3 °C for 3–4 months depending on variety (Anonymous 1968);
- 4.4 °C for 6 weeks (Lutz and Hardenburg 1968);
- 2.2–4.4 °C and 90–95% r.h. for 3–4 months (Lutz and Hardenburg 1968);
- 4 °C and 90% r.h. for 2–4 months (Mercantilia 1989);

- 2–4 °C and 90–95% r.h. for 3–4 months (Hardenburg *et al.* 1990);
- 2–4 °C and 90–95% r.h. for 2–4 months (Snowdon 1990);
- 2.2 °C and 90–95% r.h. for 60–120 days (SeaLand 1991).

Controlled atmosphere storage

Kader (1989) recommended 2–5 °C with 0–5% CO₂ and 1–2% O₂ and Lockhart *et al.* (1971) reported no detrimental effects during storage in 10% CO₂ but Hardenburg *et al.* (1990) reported that controlled atmospheres were not successful in increasing their storage life. However, Gunes *et al.* (2001) concluded that 3 °C and 98% r.h. with 21% O₂ + 30% CO₂ was the optimum storage condition. Subsequently Gunes *et al.* (2002) reported, for the cultivars Pilgrim and Stevens, that there was decreased bruising, physiological breakdown and decay of fruit in storage at 3 °C in atmospheres of 21% O₂ + 15 or 30% CO₂ compared to those stored in air. Respiration rate and weight loss was also decreased, but fruit softening increased compared to storage in air. There was also an increase in acetaldehyde, ethanol and ethyl acetate during storage in 21% O₂ + 15 or 30% CO₂ but the levels varied with cultivar and storage atmosphere with the highest in the 2 and 70% O₂ and in 100% N₂. Overall, the 30% CO₂ + 21% O₂ appeared to be optimum. No sensory analysis was included to confirm whether accumulations of fermentation products at this atmosphere were acceptable for consumers. However, they also found that the storage atmosphere did not affect the content of total phenolics or flavonoids, but the total antioxidant activity of the fruits increased overall by about 45% in fruits stored in air. This increase did not occur during storage in 30% CO₂ + 21% O₂.

Diseases

Snowdon (1990) reported that many fungi attack cranberries most of which are unusual and are unknown in other hosts. She gave the examples of black rot caused by *Ceuthospora lunata* Shear and *Strasseria oxycocci* Shear. Prange and DeEll (1997) reported that the principal storage rots were black rot, end rot, viscid rot, yellow rot and Botryosphaeria fruit rot. An experiment was conducted by dipping fruits in BioSave (a commercial preparation

containing *Pseudomonas syringae*) and coating them with carnauba wax. The cranberries were then stored at 13 °C. Coating with carnauba wax consistently resulted in lower disease incidence than non-coated fruits over a 16-week storage period. Two formulations of BioSave gave variable results but the best treatment was BioSave 110 with carnauba wax, which reduced the total decay by 60, 42 and 33%, after 4, 8 and 16 weeks, respectively, compared to the control (Chen *et al.* 2000). Storage in 100% N₂ for 3 weeks at 3.3 °C reduced the number of pathogenic species and decay, compared with fruit stored in air (Lockhart *et al.* 1971).

Custard apple

Annonaceae

Annona reticulata L., also called bullock's heart. In India and China *A. squamosa* is sometimes referred to as *custard apple* (Chen 1998, Bhadra and Sen 1999, Prasanna *et al.* 2000) and corazón because of its heart shape. Kennard and Winters (1960) commented that *A. reticulata* is often confused with the pond apple (*A. glabra* L.) whose fruit are inedible although Santos *et al.* (1998) described the pulp of pond apple as edible. It is a native of South America and the Caribbean region and has been introduced throughout the American tropics and Southeast Asia, without achieving a level of importance comparable to that of *A. cherimolia* or *A. squamosa* (Bicas *et al.* 2011). It is a deciduous tree up to about 8 m high that has flowers produced in leaf axils. It produces globose to ovoid fruits up to 12 cm in diameter with a smooth skin, which have faint outlines of the fused berries. It is brownish in colour when ripe, often with traces of red or yellow, with a sweet, creamy white pulp containing many small seeds. It is classified as climacteric. Volatile components *A. reticulata* growing in Cuba were isolated by two extraction methods and in total 180 volatile constituents were detected including β-pinene, α-pinene and germacrene D. They concluded that the presence of many terpene compounds contributed to its flavour (Pino *et al.* 2003).

Harvesting

It changes in colour as it matures from green to brownish and this and the aroma are used to

determine when to harvest. If harvested when it is still green it can have a turpentine flavour, which is said to disappear when it is ripen by exposure to ethylene (Wardlaw 1937).

Storage

Refrigerated storage recommendations include

- 7–10 °C and 85–90% r.h. for 1 week (Lutz and Hardenburg 1968);
- 5 °C and 85–90% r.h. for 6 weeks (Pantastico 1975);
- 5–7 °C and 85–90% r.h. for 4–6 weeks for Philippine varieties (Snowdon 1990);
- 12 and 85–90% r.h. for West Indian varieties (Snowdon 1990);
- 5 °C and 85–90% r.h. for 28–42 days (SeaLand 1991).

Ripening

Wardlaw (1937) recommended exposure to ethylene for improved ripening. At either 0 or 14 °C Wills *et al.* (2001) found that the time to ripen of custard apple of the cultivar Pink's Mammoth increased linearly with logarithmic decrease in ethylene concentration over the range of less than 0.005, 0.01, 0.1 1.0 and 10 $\mu\text{L L}^{-1}$, with the optimum concentration being 10 $\mu\text{L L}^{-1}$.

Dabai

Burseraceae

Canarium odontophyllum Miq. The genus *Canarium* contains about 75 species of tropical and subtropical evergreen trees up to 40–50 m tall and is native to Australia, southern Asia and tropical Africa, from southern Nigeria east to Madagascar, Mauritius, India, southern China, Indonesia and the Philippines. Several species include edible nuts and fruits including *C. album* a fruit consumed in Vietnam and Thailand and *C. odontophyllum* that is indigenous to Malaysia, Indonesia and the Philippines and grows wild along river banks except swamps and coastal sands (Ding 2011). The skin and flesh are edible after soaking in warm water. Ding and Tee (2011) reported that the fruit is steeped in water at about 60 °C for 15–20 min to soften the flesh before they are eaten. They showed that this steeping also increased TSS

and TA, as did the citric, malic and succinic acids, especially citric acid. After seeping the fruit tastes something like avocado. The *C. odontophyllum* tree grows up to about 20 m high and is androdioecious with staminate and hermaphrodite inflorescences on different trees. The staminate trees start to flower when 4 or 5 years old, while hermaphrodite trees start to flower when they are 6–8 years old (Ding 2011). The fruit is a drupe that is oval in shape with a length to diameter ratio of 1.4 with the seed contributing 61% of the fruit weight. They are white when immature turning dark purplish as they mature (Ding and Tee 2011).

Ding (2011) found that they were probably climacteric. After treating fresh dabai fruit with 10 mL L^{-1} ethylene at 20 °C, the respiration rate decreased and the rate of softening, senescence and microbial growth increased (Ding and Tee 2011). Wong (1992) found that the postharvest life of fruit was about 3 days in ambient conditions in Sarawak (about 27 °C) after which the skin became hard. Storage recommendations for fruit include the shelf life could be extended at 5 °C (Voon 2003, quoted by Ding 2011), up to 8 days at 14 °C in PE bags (Jugah 2006, quoted by Ding 2011) and 10 °C for 5–6 days in PE bags after which they turned soft and spoiled (Lau, quoted by Ding 2011).

Damsons

Rosaceae

Prunus damascena Ehrh., *P. domestica* subspecies *insititia* (L.) C.K. Schneid, *P. insititia*. They are also called damask plum. It may have arisen in the wild from crosses between the sloe (*P. spinosa*) and the cherry plum (*P. cerasifera*) or directly from forms of the sloe. Some authorities believe that it was first cultivated in the area around Damascus, hence its botanical name that means plum of Damascus, and they spread from there throughout Europe and were introduced into Britain during the Roman occupation. It is very acid but has a strong distinctive flavour and is used mainly for making jam and has been used to replace sloes in sloe gin. It produces small, white flowers and the fruit is a pyriform drupe and is probably climacteric. The skin colour ranges from dark blue to almost black with smooth yellow to green flesh. The tree is commonly used as a rootstock for

plums and can also be used for peaches and apricots. Storage conditions are probably the same as for plum (*P. domestica*).

Dates

Palmae

Phoenix dactylifera L. Its centre of origin may have been in Mesopotamia where it has been cultivated for at least 5000 years (Purseglove 1975, Harrison *et al.* 1985). Popenoe (1974) stated that it has been in cultivation for more than 7000 years and there are some 1500 varieties of dates in the world. It is widely cultivated in the Middle East and northern Africa particularly the Gulf area including Iran, Iraq and Saudi Arabia (Purseglove 1975) mainly in Islamic countries, which advises the believer to take good care of the date palm, to the point that no other tree has received the same type of attention (Popenoe 1974).

The edible portion is the fruit, which is a drupe containing a single cylindrical seed surrounded by fleshy pericarp. It is usually oblong or ellipsoidal in shape, but sometimes cylindrical or spherical. When fully mature it can be 20–110 mm long and 8–30 mm in diameter (Al Bakr 1972). The date is unusual in that the food material for the growing embryo is stored as cellulose rather than starch (Dowson 1982). The fruit grow in a bunch, which consists of a main axis with branched stalks up to a metre long. The skin of the fruit has been described as thin or thick and soft or hard. It is sometime attached to the fruit flesh and sometimes it is separated from the flesh as a little bubble. Shrinkage occurs in the skin when the fruit starts to loose moisture in the late Rutab and Tamr maturity stages (Al Bakr 1972). One characteristic of a good commercial variety is that the skin remains attached to the flesh (Al Bakr 1972). The freezing point of most fruits is usually just below the freezing point of water, but because of their very high sugar content the freezing point of dates is about -16°C .

The date palm can live for up to 100 years and reach up to 24 m to the growing point. The useful height is between 15 and 20 m and the maximum age between 44–55 years (Barreveld 1993). Over these two limits the date palm will be dangerous to climb and the yield will also decline. It has been reported to survived temperatures as low as -7°C in Baghdad, -12°C in California and -15.5°C in Texas and temperatures as

high as 50°C . The minimum temperature required for growth is 9°C (Al Bakr 1972). The date palm will flower only when the shade temperature is above 18°C and it will not produce fruit if the temperature is less than 25°C (Glasner *et al.* 1999). It is often mentioned that the date palm likes its 'feet in Heaven and its head in Hell' as it requires abundant water supply and a high air temperature for it to grow successfully (Barreveld 1993). Dates can be divided into three types:

- Soft cultivars, which contain mainly invert sugar (glucose and fructose) e.g. Khadrawy, Helawy, Sayer, Saidi, Siwi, Maktoon and Hayany and are grown in the Middle East and North Africa.
- Semi-dry cultivars contain sucrose, e.g. Amri, Zaholi and Deglet Nour, which is the most widely grown date in California.
- Dry cultivars, e.g. Sakkoti and Thoory.

Total world production in 2010 was estimated by FAO (2013) as 7,626,448 tonnes. Their chemical content was given by USDA (2012) in Table 89.

Harvesting

The soluble tannin content of the date decreased with maturity while insoluble ones increased. The speed of this process differs with variety. Also some loose the astringency at the khalaal stage and others at the rutab stage. The stages of maturity at harvest are referred to as follows:

1. *Hababouk*: The earliest stage of development.
2. *Kimiri* (Khimri, Kimri, Jimri): The fruit are green. Nearly all cultivars are astringent at this stage. Astringency is caused by a soluble tannin layer below the skin (Al Bakr 1972).
3. *Khalaal* (Khalal, Balah, Bisir, Biser): The fruits are fully grown and beginning to change colour to red or yellow. This maturity is rarely used outside the district where they grown, since the fruit are fibrous and usually still astringent.
4. *Rutab*: The colour changes to brown or black and the skin becomes loose and the flesh develops a squashy texture. The dates at this stage reach their most acceptable eating quality and are considered to be a fully ripe fruit and are consumed as fresh fruit but can be stored at 0°C (Barreveld 1993). The length of the Rutab stage on the tree is some 2–4 weeks.

Table 89 The composition of date fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	Deglet Nour	Medjool
Water (g)	20.53	21.32
Energy (kcal)	282	277
Protein (g)	2.45	1.81
Total lipid (fat) (g)	0.39	0.15
Carbohydrate, by difference (g)	75.03	74.97
Total dietary fibre (g)	8.0	6.7
Total sugars (g)	63.35	66.47
Calcium (mg)	39	64
Iron (mg)	1.02	0.90
Magnesium (mg)	43	54
Phosphorus (mg)	62	62
Potassium (mg)	656	696
Sodium (mg)	2	1
Zinc (mg)	0.29	0.44
Total ascorbic acid (mg)	0.4	0.0
Thiamine (mg)	0.052	0.050
Riboflavin (mg)	0.066	0.060
Niacin (mg)	1.274	1.610
Vitamin B-6 (mg)	0.165	0.249
Folate (µg DFE)	19	15
Vitamin B-12 (µg RAE)	0.00	7
Vitamin A (IU)	0	149
Vitamin A (µg)	10	0.0
Vitamin E (α-tocopherol) (IU)	0.05	0
Vitamin K (phyloquinone) (µg)	2.7	2.7
Fatty acids, total saturated (g)	0.032	–
Fatty acids, total monounsaturated (g)	0.036	–
Fatty acids, total polyunsaturated (g)	0.019	–

5. *Tamar*: They are brown and sufficiently dry to require no further processing. They can be stored at 0–4 °C with 70–75% r.h. for about 6 months. Benjamin *et al.* (1976) suggested that 5 °C and 70% r.h. is adequate for the storage for up to 9 months, while –3 °C with 70% r.h. was recommended by Dowson (1982) for up to a year.

The harvest time selected depends on climatic factors and consumer preference (Al Bakr 1972). In India harvesting is commonly at the khalal stage after which they are processed into dry dates, which can save them from the spoilage caused by the monsoon rain if they are left to mature further. The fruit requires intense heat on the tree to soften, but if it is combined with high humidity the fruit can fall from the bunch at the rutab stage before it reaches the Tamr stage (Glasner *et al.* 1999). Awad (2007) reported that during the harvesting season of Helali, a late season cultivar, only 30–40% of the total fruit

might normally ripen to the rutab stage on the tree and the remaining fruit fail to ripen beyond the bisir stage. Bagging bunches during the growing season significantly increased the rate of fruit ripening and increased rutab yield per bunch, with black or blue PE bags being the most effective. At the bisir stage fruit were astringent as a result of soluble tannins and removal of tannins it was necessary for the fruit to be edible. Postharvest dipping of fruit at the bisir stage in ethrel at 4.2 ml L⁻¹ and abscisic acid at 1.0 mM significantly enhanced ripening, compared to the controls. Ethanol vapour significantly hastened ripening of bisir fruit over 10 days at ambient conditions in desiccators and immersion of fruit in water for 10 h significantly increased ripening compared to the controls but to a lesser extent.

The traditional method to harvest fruit is by climbing the tree, cutting the bunch and lowering it to the ground tied to a rope usually through a pulley system. Picking platforms are available which enable the harvester to be towed around the orchard from tree to tree so the platform can be raised and lowered enabling the fruit to be picked. Cranfield University developed such a machine and tested it in Saudi Arabia in the 1990s. They were expensive and could only be used successfully on flat firm land where the trees were evenly spaced.

Respiration rate

There is an increase in respiration rate in the rutab stage that Abdel-Latif (1988) refers to as the climacteric peak, followed by a decline at the end of this stage (Table 90), but other than that it is not clear whether the fruit is climacteric or not. Postharvest application of ethylene hastened ripening and its effect increased with increased maturation of the

Table 90 Quality characteristics of some Middle Eastern varieties of dates. Respiration rates, at 20 °C, are the means for the cultivars Zahdi, Diri and Sultani (source: adapted from Abdel-Latif 1988)

Stage of maturity	Moisture (%)	Reducing sugars	Sucrose	Respiration rate (mg CO ₂ kg ⁻¹ h ⁻¹)
Kimri	80.2–83.0	33.2–34.0	3.0–4.8	215
Khalaal (Bisir)	56.8–68.0	40.0–63.2	16.0–16.7	16
Rutab	30.8–35.4	58.6–60.0	10.0–24.2	54
Tamr	19.5–26.3	45.3–76.4	7.1–28.4	2

fruit (Abdel-Latif 1988, Awad 2007). Ait-Oubahou and Yahia (1999) gave respiration rates at 20 °C as <25 ml kg h⁻¹ for khalaal stage and <5 ml kg h⁻¹ for rutab and tamar stages. Ethylene production rates at 20 °C were <0.5 µl kg h⁻¹ for khalal and <0.1 µl kg h⁻¹ for rutab and tamar stages. They found no effect of exposing yellow Barhee dates at the khalal stage to 100 ppm ethylene for up to 48 h at 20 °C and 85–90% r.h. However, khalal stage dates may respond to ethylene at 30–35 °C, which are optimum for their ripening.

Storage

At room temperature of about 26.7 °C and 75% r.h. dates can be stored for 1 month for Deglet Noor (Lutz and Hardenburg 1968). Recommendations for refrigerated storage include

- 15.6 °C for 3 months and 4.4 °C for 8 months for Deglet Noor (Lutz and Hardenburg 1968);
- 0 °C for 1 year for Deglet Noor (Lutz and Hardenburg 1968);
- -17.8 °C for more than a year for Deglet Noor (Lutz and Hardenburg 1968);
- 6.7 °C and 85–90% r.h. for 2 weeks (Pantastico 1975);
- -3 °C with 75–85% r.h. for Angasiah, Sultani, Zahdi, Barban and Um Al Balaliz (Benjamin *et al.* 1976);
- 0 °C and 75% r.h. for Sayer (Benjamin *et al.* 1976);
- 5 °C and 75% r.h. Hilwat Al Jabal for 5 months (Benjamin *et al.* 1976);
- 0 °C and 90% r.h. for 1–2 months (Mercantilia 1989);
- 0 °C and 85–90% r.h. for 1–2 months (fresh) (Snowdon 1990);
- 0 °C or lower and 70–75% r.h. for 12 months for dried fruit (Snowdon 1990);
- 0 °C and 70–75% r.h. for 165–365 days (SeaLand 1991).

Modified atmosphere packaging

Four different packaging materials were used by Butt and Al-Haq (1993) for the cultivars Khadrawi and Zaidi at the khalal stage at 28 ± 2 °C for 12 days as follows: cardboard boxes without lining, cardboard boxes with newsprint as lining, perforated PE bags, non-perforated PE bags and the control placed in

open trays. The PE bags whether perforated or not gave significantly better results compared with the other packages and control, with the non-perforated PE bags giving the best quality.

Diseases

Species of *Aspergillus*, *Alternaria* and *Penicillium* are the most common moulds found in dates. Where no obvious symptoms occur they can be detected by changes in colour, odour and flavour of the fruit (Rygg 1975). Dates with 23% or less moisture content are comparatively safe from microbiological spoilage during storage. At low temperature storage, the dates with high moisture content retained the soft texture that many consumers prefer. On the other hand, high humidity increased perishability, by increasing the activity of yeasts (Hardenburg *et al.* 1990). The yeast *Zygosaccharomyces* spp. are more tolerant of higher sugar concentration than others found in the dates. Dates that have been attacked by yeast can be detected by an alcoholic odour (Rygg 1975). Moulds are not as economically important as the yeast. They may cause large losses before and just after the fruit is harvested if rain or high humidity occurs.

Physiological disorders

Sugar spotting and darkening are the most important physiological disorder of dates. Sugar spotting is restricted entirely to the invert sugar types of date. Storage below room temperature (±20 °C) will reduce the rate of its formation. Soft varieties of dates will have spotting when the moisture percentage is in the high twenties. Higher than 33% or lower than 22% moisture content will prevent spotting (Rygg 1975). Darkening is another type of deterioration that produces some slight off-flavour. In frozen dates the darkening occurs only slightly during storage but rapidly during the thawing period (Mutlak and Mann 1984). Mutlak and Mann (1984) specified three types of reactions, the enzymatic oxidative browning of simple phenolic compounds, the non-enzymatic oxidative browning of tannin material and the non-enzymatic, non-oxidative browning of reducing sugars. Microwave heating was tried successfully to overcome the darkening effect of the enzymes. Polyphenolase was not active after 1 min of microwave heating, while peroxidase was completely

inactive in less than a minute of microwave heating. For fresh dates Rygg (1975) stated that lowering the storage temperature and reducing their moisture content could delay general darkening.

Dewberries

Rosaceae

Rubus caesius L., and the European dewberry *R. villosus* Aiton. Harrison *et al.* (1985) reported that the cultivated forms had been derived from several American species including *R. alleghaniensis*. The fruit is a collection of drupes, which are smaller and less coherent than blackberries and are black when mature and have a dull surface with a white bloom. They are classified as non-climacteric fruit and are normally harvested by hand with the receptacle in place when they have changed colour from red to black and the acid content is about 1% weight for weight. Refrigerated storage recommendations include -0.6 to 0°C and 85–90% r.h. for 5–7 days (Lutz and Hardenburg 1968) and 0.5°C and 90–95% r.h. for 2–3 days (SeaLand 1991).

Dragon fruit

Cactaceae

Hylocereus (A. Berger) Britton & Rose. Several species are grown commercially including *H. undatus* (Haw.) Britton & Rose that has red skin and white flesh, *H. costaricensis* (Weber) Britton & Rose that has red or purple flesh and *H. polyrhizus* (Weber) Britton & Rose (synonymous with *H. moncanthus*) that has red skin and red or red/violet flesh (Britton and Rose 1963, Esquivel and Araya Quesada 2012). There are yellow clones of *H. undatus* called pitaya ammarilla in Mexico and other Latin American countries but *Selenicereus megalanthus* is also called pitaya ammarilla (Mizrahi *et al.* 1997). Other common names include strawberry pear, thang loy, pitaya roja and pitahaya rouge.

Cerus triangularis is also called pitaya and dragon fruit. The fruits are a deep yellow in colour and up to 12 cm long and are made up of many tightly packed carpels each terminated in a protuberance with a small central hole and a green tip. There are two distinct varieties one with a yellow skin and

one with a fuchsia pink skin. The flesh of both is translucent white dotted with a mass of small black edible seeds and very beautiful when cut in two. It is sweet and refreshing with the seeds giving it a kind of crunchiness.

They are native to Central America and are believed to have their origin in southern Mexico, the Pacific side of Guatemala and Costa Rica and El Salvador. They are also cultivated in East Asian and Southeast Asian countries including Indonesia, Taiwan, Vietnam, Thailand, the Philippines, Sri Lanka, Malaysia, Bangladesh, Japan, southern China as well as Hawai'i, Palestine, northern Australia and Cyprus. It is being grown commercially in Israel, Vietnam, Taiwan, Nicaragua, Australia and the United States (Merten 2003, Le Bellec *et al.* 2006). It is a perennial fast growing tropical climbing cactus with a three sided stem, or sometimes they may be four or five sided, with many branched segments that may produce aerial roots. It produces a large, oblong fruit with a red peel and large green scales that turn yellow upon ripening. Esquivel and Araya Quesada (2012) found that *Hylocereus* spp. were high in betalain pigments that have been considered as an alternative to artificial food dyes and also have antioxidant properties. Ariffin *et al.* (2008) gave the composition of fatty acid-related species in Table 91.

Harvesting

Harvesting indices include skin colour, TSS, TA and days after flowering. A minimum of 32 days after flowering and a TSS:TA of 40 was suggested as a harvest index (Nerd and Mizrahi 1999). TSS of 9–15% was recommended for *H. undatus* and 8–11%

Table 91 The composition of fatty acids of dragon fruit for 100 g^{-1} fresh weight (source: Ariffin *et al.* 2008. Reproduced with permission of Elsevier)

	<i>H. polyrhizus</i> (%)	<i>H. undatus</i> (%)
Myristic	0.2	0.3
Palmitic	17.9	17.1
Stearic	5.49	4.37
Palmitoleic	0.91	0.61
Oleic	21.6	23.8
Cis-vaccenic	3.14	2.81
Linoleic	49.6	50.1
Linolenic	1.21	0.98

for *H. polyrhizus* (Nerd and Mizrahi 1999, Stintzing *et al.* 2003, Vaillant *et al.* 2005, Hoa *et al.* 2006, Esquivel *et al.* 2007). Esquivel *et al.* (2007) reported that TA ranged from 0.32 to 0.69% at full colour for genotypes grown in Costa Rica, whereas Nerd and Mizrahi (1999) reported a 0.22% TA for *H. undatus* fruit at full colour. Nerd and Mizrahi (1999) reported that the skin colour begins to change 25–30 days after flowering in both *H. undatus* and *H. polyrhizus*. At about the same time, flesh firmness approaches a minimum and eating quality approaches a maximum 33–37 days after flowering. Fruit can be harvested from 25–45 days from flowering, although 32–35 days were considered optimum in Israel. In other areas Merten (2003) recommended 40–45 days in California, 35–50 in Hawai'i (Zee *et al.* 2004) and 28–32 in Vietnam (Hoa *et al.* 2006).

Postharvest treatment

Ali *et al.* (2013) found that postharvest treatment with 1% submicrometer chitosan dispersions with 600 nm droplet size before storage $10 \pm 2^\circ\text{C}$ and $80 \pm 5\%$ r.h. for 28 days reduced anthracnose disease and maintained their quality better than those not treated.

Postharvest physiology

Nerd and Mizrahi (1999) reported that they were non-climacteric fruit with ethylene production rates of $0.025\text{--}0.091\ \mu\text{l kg}^{-1}\text{ h}^{-1}$. Le *et al.* (2000b) found that exposure to ethylene did not initiate colour development. The maximum respiration rate of *H. undatus* and *H. polyrhizus* occurred during early fruit growth and the rate for mature fruit was given as $95\text{--}144\ \text{mg CO}_2\ \text{kg}^{-1}\text{ h}^{-1}$ at 20°C (Nerd and Mizrahi 1999) and $75\text{--}100\ \text{mg CO}_2\ \text{kg}^{-1}\text{ h}^{-1}$ at 23°C (Le *et al.* 2000a). As the fruit matured, acidity reached a peak and TSS increased to about 14% just as the skin colour change occurred, then declined 25–30 days after flowering (Nerd and Mizrahi 1999, Le *et al.* 2000a).

Storage

They can suffer from chilling injury. After storage at 6°C for 14 days Nerd and Mizrahi (1999) found that chilling injury occurred when they were transferred to 20°C . The symptoms included deterioration and

darkening of the skin and translucency of the flesh and an inferior taste. They found that harvest maturity affected susceptibility to chilling injury. In storage at 6°C fruit harvested 25 days from flowering suffered from chilling injury after 7 days while those harvested after 30–35 days it occurred after 17 days. They therefore recommended storage at 10°C . Le *et al.* (2000a) also recommended 10°C for about 14 days while at 5°C and 90% r.h. they could be stored 17 days if they had been harvested 30–35 days after flowering. Paull (2004) recommended 10°C for a maximum of 14 days. TSS was 12.2% after 2 weeks storage at 14°C (Nerd and Mizrahi 1999). Nerd and Mizrahi (1999), however, recommended 6°C for the yellow pitaya *S. megalanthus*.

Modified atmosphere packaging

Fruit harvested 28–30 days after flowering and stored in plastic film bags with an O_2 transmission rate $4000\ \text{ml m}^{-2}\text{ day}^{-1}$ could be stored for 35 days at 10°C compared to 14 days for those not in plastic film bags (Le *et al.* 2000b). Fruit harvested 40 days from flowering and stored in plastic film bags had only half the storage life of those harvested 28–30 days after flowering.

Diseases

Bacterial (*Xanthomonas campestris*) and *Dothiorella* spp. diseases have been reported (Barbeau 1990). Postharvest diseases have also been associated with *Fusarium lateritium*, *Aspergillus niger* and *Aspergillus flavus* infections (Le *et al.* 2000a).

Pests

Hoa *et al.* (2006) reported that *H. undatus* are a host of the fruit fly *Bactrocera* spp. in Vietnam. In order to conform to the biosecurity requirements of importing countries they treated the cultivar Binh Thuan with hot air at fruit core temperatures 46.5°C for 20 min. They found that fruit quality was not detrimentally affected during 2–4 weeks subsequent storage at 5°C in sealed PP bags and shelf life at 20°C . Wall and Khan (2008) compared different exposures of fruit to X-ray irradiation and found that doses 800 Gy or less would ensure visual and compositional quality while providing quarantine security. Surface

colour, peel injury and bract appearance differed among the three clones they tested but in all cases, visible changes were minor. Fruit decay was absent or minimal, and disease ratings were not affected by irradiation during subsequent storage at 10 °C for 12 days.

Durian

Bombaceae

Durio zibethinus Murray, synonymous with *D. acuminatissima* Merr. The durian is believed to be native to Borneo and Sumatra. It is found wild or semi-wild in south Tenasserim, Lower Burma and around villages in peninsular Malaya. Durian is commonly cultivated alongside roads or in orchards from south-eastern India and Sri Lanka to New Guinea. Four hundred years ago, there was a lively trade in durians between Lower Burma to Upper Burma where they were prized in the Royal Palace. Thailand and South Vietnam are important producers of durians. Morton (1987) reported that it was believed to be native to Borneo and Sumatra and is found wild or semi-wild in south Tenasserim, lower Burma and around villages in the Malaysia/Thai peninsular. However, Purseglove (1975) reported that it originated in Malaysia and is grown throughout south-east Asia

mainly cultivated in Sri Lanka, southern India, southern Burma, Thailand, Cambodia, Vietnam, Malaysia, Indonesia, Borneo, Philippines and New Guinea but has rarely been successfully grown elsewhere. The Welsh naturalist Alfred Russell Wallace considered in the 19th century that 'it was worth a journey to the East, if only to taste the fruit'. The fruit was described in Blackie's Modern Encyclopaedia of 1896 'The smell is offensive, like putrid animal matter, but with this is associated the most delicious flavour, which places it, notwithstanding the odour, in the opinion of many, in the foremost place among tropical fruit.' It has also been described as a strong unpleasant smell, a combination of over ripe cheese, rotten onions, turpentine and bad drains which will taint any other crop with which it is stored.

The trees are huge, up to 30 m high or more and they begin fruiting about 7 years after propagation. The flowers are produced directly on the trunk or branches and are white, have an unpleasant odour and are borne in cymes. The fruit is ovoid, foetid and spiny with the walls split into five valves and greenish yellow in colour (Figure 88). They have a creamy coloured custard-like pulp that are up to 25 cm in diameter. There are over 300 named varieties of durian in Thailand (Morton 1987). She also gave the chemical content in Table 92.



Figure 88 Durian fruit on sale in a Malaysian market with the fruit cut into two to show the pulp and seeds.

Table 92 The composition of durian fruit for 100 g⁻¹ fresh weight (source: Morton 1987)

	Fresh arils	Dried arils
Calories	144	–
Moisture	58.0–62.9 g	18.0 g
Protein	2.5–2.8 g	–
Fat	3.1–3.9 g	3.0–6.0 g
Sugars	(approximately) 12.0 g	37.0–43.0 g
Starch	(approximately) 12.0 g	8.0–13.0 g
Total carbohydrates	30.4–34.1 g	–
Fibre	1.7 g	–
Ash	1.1–1.2 g	3.0 g
Calcium	7.6–9.0 mg	–
Phosphorus	37.8–44.0 mg	–
Iron	0.73–1.0 mg	–
Carotene	0.018 mg	–
(as vitamin A)	20–30 IU	–
Thiamine	0.24–0.352 mg	–
Riboflavin	0.20 mg	–
Niacin	0.683–0.70 mg	–
Ascorbic acid	23.9–25.0 mg	–
Vitamin E	High	–

Harvesting

Purseglove (1975) claimed that it is not considered mature until it has fallen from the tree. However, in practice they are harvested for commercial purposes from the tree before they are fully mature. Vilcosqui and Dury (1997) recommended that fruits are harvested 95–130 days after flowering. The criteria taken into account in judging maturity are the changes in skin colour, which turns from dark to light green as it approaches maturity then to yellow and sometimes with brown tips. The spines become less stiff as the fruit matures and can be bent more easily. An abscission layer is produced at the base of the fruit stalk, which means as it matures it is more easily detached from the tree. As the fruit matures it has a more hollow sound when it is tapped. The smell emitted by the fruit indicates that it has begun to ripen. The decision is usually dependent on the skill and experience of the harvester. Images obtained by X-ray CT and NMR showed that both methods were suitable for detecting differences among immature, mature and over-ripe fruit and internal disorders and rotten pulp in the cultivar Murray and NMR imaging could be used to identify the physiological disorder called water core (Yantarasri *et al.* 1998). In south-east Asia it is common practice to tap the fruit to judge its ripeness.

Prestorage treatments

Various coating materials tested by Sriyook *et al.* (1994) were shown to delay dehiscence and ripening. A sucrose fatty acid ester at a concentration of 1% gave the best result in the cultivar Chanee. All coating materials reduced weight loss to about 7–14% below that of control fruits. Fruits coated with the sucrose fatty acid ester or 100% apple wax had higher internal CO₂ concentrations than fruits coated with any other coating. Pulp from the cultivar Mon Thong was exposed to 0, 50, 100, 200 and 500 ppb of 1-MCP for 12 h at 20 °C and then stored in 15 µm PVC film at 4 °C by Sudto and Uthairatanakij (2007). After 8 days storage at 20 °C treated fruits were firmer than non-treated. About 50 ppb was the most effective in delaying the accumulation of CO₂ inside the packages, but none of the treatments affected ethylene production. Treatment with 1-MCP resulted in a reduction of the starch content and an increase in soluble solids and the activity of lipoxygenase.

Postharvest physiology

The ripening fruits exhibited a very marked climacteric rise in respiration at 22 °C and a parallel increase in ethylene evolution, immediately upon harvest (Tongdee *et al.* 1990). The respiration rate and ethylene production at harvest and the peak climacteric respiration rate were higher in fruits harvested at a more advanced stage. They found that their respiration rate was 80–450 mg CO₂ kg⁻¹ h⁻¹ at 22 °C.

Storage

Purseglove (1968) suggested that they should be eaten immediately after they have fallen from the tree otherwise they will turn rancid. However, ripe fruits collected after they have fallen to the ground undergo dehiscence within 3 days (Suhaila 1990). Fruits harvested when ripe can be stored in ambient temperature for 4 days (Vilcosqui and Dury 1997). Pan (2008) reported that in south China it could be stored in air at ambient temperatures for 3 weeks. During storage at 27 °C and either 65 or 95% r.h. it was found that there was increased fruit dehiscence at the lower humidity (Sriyook *et al.* 1994). Recommended refrigerated storage conditions include

- 3.9–5.6 °C and 85–90% r.h. for 6–8 weeks (Pantastico 1975);
- 4–5 °C and 85–95% r.h. for 30–35 days (Salunkhe and Desai 1984);
- 4–6 °C and 85–90% r.h. for 1–2 months (Snowdon 1990);
- 3.9 °C and 85–90% r.h. for 42–56 days (SeaLand 1991);
- 15 °C for 3 weeks for ripe fruits (Vilcosqui and Dury 1997).

In contrast to some of the above work Romphophak *et al.* (1997) in Thailand showed that fruits harvested 118 days after anthesis developed chilling injury symptoms at 13.5° but could be stored for 15 days at 16.5°. Fruits harvested 125 days after anthesis could be stored for 15 days at 13.5°, but only for 10 days at 16.5 °C. Chilling injury symptoms were described as black discolouration on the fruit surface, especially the grooves between the thorns, and occurred after storage at 5 °C for 2 weeks (Romphophak and Palakul 1990). Kosiychinda (1968) described chilling injury symptoms as the rind turning dark brown, and these symptoms occurred in 1½ days at 1 °C, 4 days at 4 °C and 14 days at 11 °C.

Controlled atmosphere storage

Ripening was inhibited in the cultivars Chanee, Kan Yao and Mon Tong stored in 5–7.5% O₂ at 22 °C compared to air but ripened normally when fresh air was subsequently introduced. Storage in 5–7.5% O₂ did not affect ripening in fruits harvested at an advanced stage of maturity, but fruits stored in 2% O₂ failed to resume ripening when removed to air. Storage in 10 or 20% CO₂ did not influence the onset of ripening or other quality attributes of ripe fruits and it resulted in little or no reduction in ethylene production (Tongdee *et al.* 1990).

Modified atmosphere packaging

Ripe durians, collected after they have fallen to the ground, then wrapped in a double layer of LDPE film gave the best results during storage at ambient temperature or at 8 °C. At ambient temperature, shrink wrapping prolonged the shelf life of fruits up to 15 days and percentage dehiscence was low. At 8 °C, shrink wrapping prolonged the shelf life to 8 weeks but 20% of fruits had dehisced. Shrink wrapping also

reduced moisture loss during storage and reduced the release of the characteristic strong durian odour (Suhaila 1990).

Ripening

The ambient conditions where it is grown in south-east Asia appear to be satisfactory for ripening. Ketsa and Pangkool (1995) showed that 24–30 °C gave satisfactory ripening of the cultivar Chanee. They subsequently experimented with Chanee fruits harvested 100, 105 or 110 days after full bloom (Ketsa and Pangkool 1996). They were treated with 0, 200 or 400 µl L⁻¹ ethylene at 30–33 °C and 60–66% r.h. for 24 h. Ethylene treatment significantly affected firmness, β-carotene, soluble solids, total sugars and starch content of the pulp 2 days after treatment. Fruit harvested 110 days after full bloom responded to ethylene treatment better than those harvested 100 or 105 days after full bloom. However, 100 µl L⁻¹ ethylene increased fruit dehiscence during storage at 27 °C (Sriyook *et al.* 1994).

Disease

Fruit diseases caused by *Collectrichum*, *Fusarium*, *Lasiodiplodia*, *Phomopsis*, *Phytophthora*, *Rhizopus* and *Sclerotium* have been reported. *Phytophthora* spp. is a major cause of rot that leads to high losses during rainy weather and if fruit come in contact with soil. Fruit left on the ground can also be attacked by *Sclerotium rolfsii*. Sanitation, avoidance of mechanical injury and fungicide can be used for control (Tongdee *et al.* 1987, Lim 1990, Snowdon 1990).

Easy peeling citrus fruits

Rutaceae

Citrus reticulata Blanco, *C. unshiu* (Swingle) Marow. Some reviewers give storage for unspecified types of *C. reticulata* and *C. unshiu*, so the following is information on general storage, but see also under tangerine, clementine, mandarin and satsuma. Recommendations include

- 4.7–7 °C and 85–90% r.h. for 3–6 weeks (Anonymous 1967);
- 0 °C and 85–90% r.h. for up to 4 weeks (Lutz and Hardenburg 1968);

- 4 °C and 90–95% r.h. for 2–4 weeks (Hardenburg *et al.* 1990);
- 4–5 °C and 90% r.h. for 6–8 weeks (Snowdon 1990);
- 4.5–7 °C and 90% r.h. for 3–5 weeks for California, Arizona fruit (Snowdon 1990);
- 0–4.5 °C and 90% r.h. for 3–5 weeks for Florida and Texas fruit (Snowdon 1990).

Elderberry

Caprifoliaceae

Sambucus canadensis L. synonymous with *S. nigra* L. Other common names include elder, black elder, European elderberry, European black elderberry and common elder. They are natives of Europe, Asia and North America. The name of the genus is derived from a musical instrument called a sambuca and in Italy a flute called a sampogna is made from the young shoots with the soft pith removed. Elder flowers and fruits are used for wine and other drinks including herbal tea and they have medicinal properties. Harokopakis *et al.* (2006) reported that elder flower extract displayed useful anti-inflammatory properties that could be exploited therapeutically for the control of inflammation in human periodontitis. It is a deciduous shrub or small tree usually growing up to 6 m with light grey bark when young, changing to a coarse grey outer bark with lengthwise furrowing. It is deciduous shrub and both the flowers and the fruit are edible. Both are used for making soft drinks syrup and wine. The hermaphrodite flowers are borne in large corymbs up to 25 cm diameter with individual white flowers 5–6 mm diameter. The fruit is up to 5 mm diameter, produced in clusters and are green, turning black when ripe but are astringent and not very edible and therefore are usually processed. The medicinal Jelly Ear fungus is frequently found on Elder trees. The chemical content was given by USDA (2012) in Table 93.

For the fruit harvesting is when they have turned black and shiny. Harvesting is by hand removing the whole cluster by clipping it from the tree. It is not produced in commercial orchards and is mainly collected from the wild so the only information on postharvest aspects is for the mature berries and storage was recommended as –0.5 °C and 90–95% r.h. for 5–14 days (SeaLand 1991).

Table 93 The composition of elderberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	79.80 g	Zinc	0.11 mg
Energy	73 kcal	Total ascorbic acid	36.0 mg
Protein	0.66 g	Thiamine	0.070 mg
Total lipid (fat)	0.50 g	Riboflavin	0.060 mg
Carbohydrate, by difference	18.40 g	Niacin	0.500 mg
Total dietary fibre	7.0 g	Vitamin B-6	0.230 mg
Calcium	38 mg	Folate	6 µg DFE
Iron	1.60 mg	Vitamin B-12	0.00 µg
Magnesium	5 mg	Vitamin A	30 µg RAE
Phosphorus	39 mg	Vitamin A	600 IU
Potassium	280 mg	Fatty acids, total saturated	0.023 g
Sodium	6 mg	Fatty acids, total monounsaturated	0.080 g
		Fatty acids, total polyunsaturated	0.247 g

Emblic

Euphorbiaceae

Phyllanthus emblica L. synonymous with *Emblia officinalis* Gaertn. Other common names include aonla, amla, emblic myrobalan, Indian gooseberry and Malacca tree. It is a native of tropical Asia and adjoining islands. The fruit are produced on a tropical tree that can grow up to 18 m in height, with a crooked trunk and spreading branches. The flowers are greenish-yellow. The fruit is globular and 2 or 3 cm in diameter with six vertical furrows and thin pale yellow or greenish skin when mature. The flesh is semi-transparent and acidic and contains a three-celled stone inside which are six seeded (Kenard and Winters 1960, Morton 1987). In the Indian sub-continent they are used in making pickles, jellies and preserves. They are also used in making quality inks, ordinary dyes and shampoos and in tanning industry. In addition, the dried fruit is used in Ayurvedic and Unani system of medicine for various ailments such as fever, liver disorder, indigestion, anemia, heart complaints and urinary problems (Bhattacharjee 2004). The fruit is sour, astringent and it is quite fibrous. In India it is common to soak them in salt water and turmeric to make them more palatable. Bhattacharjee (2004) reported that they were probably the richest known natural source of vitamin C; one fruit contained as much as 24 oranges as well as calcium, iron, phosphorus, carotene, thiamine,

Table 94 The composition of emblic fruit for 100 g⁻¹ fresh weight from the Finlay Institute Laboratory, Havana, Cuba (source: Morton 1987)

Moisture	77.1 g	Fibre	1.9 g
Carotene	0.01 mg	Tryptophan	3.0 mg
Protein	0.07 g	Ash	0.5 g
Thiamine	0.03 mg	Methionine	2.1 mg
Fat	0.2 g	Calcium	12.5 mg
Riboflavin	0.05 mg	Lysine	17.0 mg
Carbohydrates	21.8 g	Phosphorus	26.0 mg
Niacin	0.18 mg	Ascorbic acid	625 mg
		Iron	0.48 mg

riboflavin, niacin and tannins. Published ascorbic acid data varies e.g. in Puerto Rico it was 625 mg 100 g⁻¹, fruits from one tree in Avon Park Florida had 467 mg 100 g⁻¹, two adjacent trees in Homestead Florida had 1130 and 1325 mg 100 g⁻¹, Dr Margaret Mustard reported an average of 1561 100 g⁻¹ and a high of 1814 mg 100 g⁻¹ in seven samples analysed (Morton 1987) and 590 mg 100 g⁻¹ in India (Pareek and Kitinoja 2011). Morton (1987) also quoted work at the Central Drug Research Institute, Lucknow in India that showed ascorbic acid in emblic fruit was considered highly stable, apparently protected by tannins (or leucoanthocyanins) that retard oxidation. It was shown that they contained 13 tannins plus three or four colloidal complexes. In juice extracted from the fresh fruit, the ascorbic acid was stable for at least a week. Fresh juice stored at 2 °C lost only 14% ascorbic acid after 45 days. The chemical content was given by Morton (1987) in Table 94. Pareek and Kitinoja (2011) gave the analysis on a fresh weight basis as moisture as 84.56%, reducing sugar 2.45%, non-reducing sugars 0.79%, protein 0.93%, calcium pectate 0.55% and galloannic acid as 0.50%.

Harvesting and handling

Chundawat (1990) reported that vegetatively propagated trees begin to produce a commercial crop after 6–8 years while those propagated by seed may take 10–12 years and harvest maturity is judged on when the seed colour changes from creamy white to black or the exocarp becomes translucent. However, harvest maturity was reported by Pareek and Kitinoja (2011) as being not fully researched but methods used in other fruit were applicable including skin colour, TSS, TA and specific gravity. For specific

gravity some work of Singh *et al.* (2006) at the Central Horticultural Research Station in Gujarat (quoted by Pareek and Kitinoja 2011) showed that optimum specific gravity varied with cultivar including 1.02 for Chakaiya, 1.03 for NA-7, Krishna and Kanchan, 1.06 for Gujarat-2, 1.07 for Agra Bold and 1.08 for Gujarat-1, Banarasi and Francis. The berries are harvested by hand often after climbing to upper branches that are bearing the fruits. Morton (1987) reported that in India, people shake down the fruits that are ready to fall and gather from the ground those that have already fallen and the fruit stand handling well.

Postharvest physiology

Pareek and Kitinoja (2011) reported that they were non-climacteric fruit and their respiration rate ranged from 70 to 82 mg CO₂ kg⁻¹ h⁻¹.

Storage

Recommendations for storage were 0–1.7 °C and 85–90% r.h. for 8 weeks (Anonymous 1967, Pantastico 1975). However, in more recent work Pareek and Kitinoja (2011) found that they suffered from chilling injury whose symptoms were initial brown discoloration of the skin often accompanied by pitting and water-soaked lesions. In more severe cases the flesh can also be affected. They found that these symptoms occurred in storage below 6 °C and recommended storage at 12 °C.

Diseases

The following fungi were isolated most frequently from fruits from three markets in the Indian sub-continent by Akhund *et al.* (2010): *Aspergillus* (five species), *Penicillium* (four species), *Fusarium* (four species), *Alternaria* (four species), *Cladosporium* (five species) and *Curvularia* (three species). *A. niger* and *A. flavus* were the most common fungi isolated from fruits of all three localities. Morton (1987) reported infection with *P. islandicum* in storage and that pre-processing treatment with 0.01% sulphur dioxide or sodium benzoate prolonged their keeping quality. Akhund *et al.* (2010) pointed out that some species produce toxic metabolites and Chundawat (1990) reported that *P. oxalicum* and *P. islandicum* had been shown to infect fruit both in the orchard and during marketing.

Feijoas

Myrtaceae

Feijoa sellowiana Berg., synonymous with *Acca sellowiana* (O.Berg) Burret, also called Pineapple Guava. It originated in the highlands of southern Brazil and is also found wild in eastern Paraguay, Uruguay, northern Argentina and Colombia. The German botanist Otto Karl Berg named feijoa after João da Silva Feijó, a Portuguese botanist born in Brazil. The fruit are classified as climacteric and are oblong in shape and up to 5 cm in diameter and are produced on a large bush. The skin is reddish brown and contains a whitish pulp. When the fruit is cut across there is a four-pointed star shape in the middle that contains small seeds. The flavour of the fruit resembles the flavour of pineapple, hence one of its common names, combined with strawberry. The chemical content was given by USDA (2012) in Table 95 and Morton (1987) in Table 96.

Harvesting

As it matures the fruit turns from green to reddish brown and this colour change is used to determine when to harvest. They can be harvested when fully grown but still green and ripened after harvest (Klein and Thorpe 1987).

Table 95 The composition of feijoas fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	84.94 g	Total ascorbic acid	32.9 mg
Energy	55 kcal	Thiamine	0.006 mg
Protein	0.98 g	Riboflavin	0.018 mg
Total lipid (fat)	0.60 g	Niacin	0.295 mg
Carbohydrate, by difference	12.92 g	Vitamin B-6	0.067 mg
Total dietary fibre	6.4 g	Folate	23 µg DFE
Total sugars	8.20 g	Vitamin B-12	0.00 µg
Calcium	17 mg	Vitamin A	0 µg RAE
Iron	0.14 mg	Vitamin A	6 IU
Magnesium	9 mg	Vitamin E	0.16 mg
		(α-tocopherol)	
Phosphorus	19 mg	Vitamin K	3.5 µg
		(phyloquinone)	
Potassium	172 mg	Fatty acids, total saturated	0.148 g
Sodium	3 mg	Fatty acids, total monounsaturated	0.081 g
Zinc	0.06 mg	Fatty acids, total polyunsaturated	0.194 g

Table 96 The composition of feijoas fruit for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	84%	Sodium	5 mg
Protein	0.9%	Calcium	4 mg
Fat	0.2%	Magnesium	8 mg
Total carbohydrates	10%	Phosphorus	10 mg
Sugar	6%	Iron	0.05 mg
Ascorbic acid	28–35 mg	Potassium	166 mg
Ash	0.5%		

Prestorage treatments

Pesis and Sass (1994) showed that exposure of fruits of the cultivar Slor to total nitrogen or total CO₂ for 24 h prior to storage induced the production of aroma volatiles including ethyl acetate and ethyl butyrate as well as acetaldehyde and ethanol.

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for 7–10 days (Mercantilia 1989). Refrigerated storage recommendations include

- 4 °C and 90% r.h. for 4 weeks followed by a shelf life of 5 days at 20 °C for the cultivars Apollo, Gemini, Marion and Triumph (Thorpe and Klein 1987);
- 10 °C and 90% r.h. for 3 weeks (Mercantilia 1989);
- 5 °C and 95–100% r.h. for 14–21 days (SeaLand 1991).

Controlled atmosphere storage

East *et al.* (2009) found for the cultivar Unique stored at 5 °C that a combination of low O₂ and low CO₂ provided the largest benefit in reducing weight loss, the change in hue values and the incidence of blemished fruit as compared to storage in air. Aziz Al-Harthy *et al.* (2009) reported that storage of the cultivar Opal Star at 4 °C in 2% O₂ + 0% CO₂, 2% O₂ + 3% CO₂, 5% O₂ + 0% CO₂ or 0% O₂ + 3% CO₂ for up to 10 weeks retained their green colour while those stored in air went yellow. CA also had some effects on reducing the rate of softening compared with those stored in air with 2% O₂ + 0% CO₂ or 5% O₂ + 0% CO₂ giving the best results.

Fig

Moraceae

Ficus carica L. It is native to the arid regions of Asia Minor from where it spread to the Mediterranean

Table 97 The composition of fig fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	79.11 g	Thiamine	0.060 mg
Energy	74 kcal	Riboflavin	0.050 mg
Protein	0.75 g	Niacin	0.400 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.113 mg
Carbohydrate, by difference	19.18 g	Folate	6 µg DFE
Total dietary fibre	2.9 g	Vitamin B-12	0.00 µg
Total sugars	16.26 g	Vitamin A	7 µg RAE
Calcium	35 mg	Vitamin A	142 IU
Iron	0.37 mg	Vitamin E	0.11 mg
		(α-tocopherol)	
Magnesium	17 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	14 mg	Vitamin D	0 IU
Potassium	232 mg	Vitamin K	4.7 µg
		(phylloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.060 g
Zinc	0.15 mg	Fatty acids, total monounsaturated	0.066 g
Total ascorbic acid	2.0 mg	Fatty acids, total polyunsaturated	0.144 g

region and has been an important fruit of commerce in that region from ancient times. The Egyptians grew it in 4000 BCE and they were introduced from Europe to North America as early as 1600 CE (Morton 1987). It is a shrub or low spreading deciduous tree. The flowers are small and are commonly produced twice in the season, the first produced on the ends of the shoot of the preceding year's growth and the second in the axils of the leaves of the new growth. The fruit is a synconium that is formed by the swelling of the entire female inflorescence. The fruit will freeze at about -3.2 to -2.4 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 97. Total world production in 2010 was estimated by FAO (2013) as 1,059,322 tonnes.

Harvesting and handling

Wardlaw (1937) indicated that they should be allowed to mature on the tree before harvesting. Depending on the cultivar this is judged to be when the skin turns light green and they feel just soft to the touch, otherwise they will not ripen in storage. In work in Turkey the quality of unripe figs of the cultivar Bursa Siyahi was poorer than that of ripe figs

both before and after storage. Figs harvested about 2 days before being fully ripe had poor taste, low total soluble solids and high acidity and the pulp and skin colour were not fully developed (Celikel and Karacali 1998). Dampness and cool conditions at harvest or ripening at too low a temperature may cause them to split (Pantastico 1975, Wardlaw 1937). They are usually cut from the tree by hand with a 2–3 cm stalk. They very easily bruise and must be handled with great care (Wardlaw 1937). In order to maximize their postharvest life forced air pre-cooling was recommended by Turk (1989) with the most appropriate method would be forced air at high humidity.

Prestorage treatments

Wardlaw (1937) found that coating with paraffin wax delayed deterioration during transport. However, this treatment would not be acceptable commercially since the whole of the fruit is eaten and once applied it would not be possible to get rid of the flavour of paraffin wax. Pretreatment with 4% calcium chloride improved retention of fruit colour, texture and increased accumulation of ascorbic acid and checked the growth of both mesophilic aerobic bacteria, yeast and moulds during subsequent storage at 1 ± 0.5 °C and 95–98% r.h. (Irfan *et al.* 2013). Fruits of the cultivar Bardakci were harvested at optimum harvest maturity and half were treated with 10 ppb 1-MCP at 20 °C for 12 h and the other half left non-treated and both were stored at 0 °C with 90–92% r.h. for 15 days by Gözlekçi *et al.* (2008). They found that the 1-MCP treatment slowed fruit softening but had no effect on TA and TSS.

Postharvest physiology

Wills *et al.* (1989) and Crisosto and Kader (2002b) classified it as a climacteric fruit but Biale (1960) classified it as non-climacteric. Crisosto and Kader (2002b) reported that they were slightly sensitive to ethylene on stimulating softening and decay, especially if stored at 5 °C or higher temperatures. Unripe fruits had a higher respiration rate than ripe fruits 1 day after storage at 20 °C (Celikel and Karacali 1998). Their respiration rates were given by Crisosto and Kader (2002b) in Table 98.

Table 98 Respiration rate of fig fruit (source: adapted from Crisosto and Kader 2002b)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	4–8
5	10–16
10	18–24
20	40–60

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for 1–2 days (Mercantilia 1989). Refrigerated storage recommendations include

- 0 °C for 44 days (Wardlaw 1937);
- 7.2 °C for 1 month (Wardlaw 1937);
- 10 °C and 85% r.h. for 21 days (Wardlaw 1937);
- 1.7 and 4.4 °C for 14 days (Australia) (Wardlaw 1937);
- –0.6 to 0 °C and 85–90% r.h. for 7–10 days (Lutz and Hardenburg 1968);
- 0–1.7 °C and 85–90% r.h. for 7 weeks with 11.5% weight loss (Pantastico 1975);
- 0 °C and 90% r.h. for 1–2 weeks (Mercantilia 1989);
- 1 °C and 85–95% r.h. for 6 weeks for the cultivar Bursa Siyahi if harvested at the firmness stage of 6 lbs inch⁻² and precooled (Turk 1989);
- 7–10 °C and 80–85% r.h. for 15–20 days (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1990);
- 0 °C and 85–90% r.h. for 7–10 days (SeaLand 1991);
- 1 °C and 85–90% r.h. for 4 weeks for fruits harvested when fully ripe (Celikel and Karacali 1998);
- –1 to 0 °C with 90–95% r.h. for 1–2 weeks for the cultivars Black Mission and Calimyrna grown in California (Crisosto and Kader 2002b).

Rodov *et al.* (2012) observed that figs grown in nethouses had poor colouration. They studied the effects of postharvest exposure of the cultivar Brown Turkey to pulsed light emitted by a high-energy xenon flash lamp and found that exposure of poorly coloured figs to pulsed light for just 10–90 s enhanced their red colouration. After 5 days storage in the dark at 20 °C, the anthocyanin content of the skin

of fruit exposed to 90–300 s of pulsed light was 20 times higher than that observed in fruit that had not been exposed and approached the level typical of the cultivar. Also pulsed light treatments caused an increase in the fruit total phenolic content that could not be attributed solely to anthocyanins, suggesting that production of other phenolic compounds might also be stimulated by pulsed light.

Controlled atmosphere storage

Storage in high CO₂ atmospheres reduced mould growth without detrimentally affecting the flavour of the fruit (Wardlaw 1937). Enriched CO₂ was suggested as a supplement to refrigeration by Hardenburg *et al.* (1990). Other storage recommendations include

- 0 °C with 15% CO₂ with 5% O₂ (SeaLand 1991);
- 0–5 °C with 15% CO₂ and 5% O₂ (Kader 1985);
- 0–5 °C with 15–20% CO₂ and 5–10% O₂ (Kader 1989, 1992);
- –1 to 0 °C 5–10% O₂ + 15–20% CO₂ for 3–4 weeks for Black Mission and Calimyrna grown in California. Figs exposed to less than 2% O₂ and/or greater than 25% CO₂ developed off-flavours due to fermentation (Crisosto and Kader 2002b).

Tsantili *et al.* (2003) stored the cultivar Mavra Markopoulou at –1 °C in either air or 2% O₂ + 98% N₂. Those stored in air became soft during storage for longer than 8 days but those in CA remained in much better condition.

Modified atmosphere packaging

Park and Jung (2000) found that storage in PE bags retained fruit quality better. They also stored the cultivar Masudohin sealed in 0.04 mm PE bags with 0, 60, 70, 80 or 90% CO₂ at 0 °C for up to 20 days. During the first 4 days of storage the atmosphere in the bags varied between 12.3 and 14.0% O₂ and 10.0 and 14.2% CO₂ depending on the CO₂ treatment and then subsequently stabilized at 13.2–14.0% O₂ and 1.1–1.2% CO₂. Ethylene content in PE bags increased in the first 2 days and was higher in the control compared to those treated with CO₂. The CO₂-treated fruit were firmer, had better visual quality and reduced incidence of decay.

Disease

Crisosto and Kader (2002b) identified the following as the principle postharvest diseases:

- Alternaria rot, caused by *Alternaria tenuis* appears as small, round, brown/black spots over the fruit surface.
- Black mould rot, caused by *Aspergillus niger*, appears as dark or yellowish spots in the flesh with no external symptoms. At advanced stages the skin and flesh turn slightly pink colour and white mycelia with black spore masses are produced on the skin.
- Endosepsis (soft rot), caused by *Fusarium moniliformis*, appears in the cavity of the fruit making the pulp soft, watery and brown with sometimes an offensive odour.

Cantín *et al.* (2011) identified *Alternaria* spp., *Rhizopus* spp., *Botrytis* spp. and *Penicillium* spp. on the fruit surface and reported that SO₂ reduced decay and extended the market life of fresh figs, but in some cases, SO₂ generating pads resulted in skin bleaching. They developed a protocol for gaseous SO₂ that allowed the application of very low specific concentration × time products of SO₂ and evaluated different SO₂ concentration × time products that showed that a product of 25 µl L⁻¹ h⁻¹ at 20 °C provided the best compromise between decay control and fruit injury. They concluded that SO₂ can be used to control postharvest rots and therefore increase the market life of fresh figs. Fruit of the cultivar Bursa Siyahi were fogged with chlorine dioxide for 60 min at room temperature and then stored either in air or modified atmosphere bags for 7 days at 1 °C followed by shelf life of 2 days at 20 °C by Karabulut *et al.* (2009). Chlorine dioxide at 500–1000 µl L⁻¹ significantly reduced natural incidence of decay, most of which was grey mould (*B. cinerea*). Modified atmosphere packaging did not improve the efficacy of fogging in reducing decay incidence and treatments did not affect the visual quality and taste of fruit. Storage in atmospheres containing high CO₂ reduced mould growth without affecting the flavour of the fruit (Wardlaw 1937). Crisosto and Kader (2002b) recommended careful handling, good sanitation and prompt precooling to 0 °C for control of postharvest diseases.

Sunburn can cause the development of dark brown blotches or bands during subsequent storage (Pantastico 1975).

French sorrel

Polygonaceae

Rumex acetosa L., *R. scutatus* L. Other common names include Sorrel, Spinach Dock and Narrow-Leaved Dock. It is a perennial plant with a deep taproot. It grows quickly to a clump up to 1 m across. The leaves are harvested when young and used in salads. The flavour is slightly bitter or tangy, spicy with a hint of lemon. The sharp flavour is due to oxalic acid. Vacuum precooling and packaging in sealed PE lined cartons were recommended by Aharoni *et al.* (1989). They also found that chlorophyll degradation was delayed effectively when exposed to 5% CO₂ in air in a flow-through system. Aharoni *et al.* (1989) studied freshly harvested sorrel under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in sealed PE lined cartons resulted in a marked retardation of both yellowing and decay. However, sealed film packaging was applicable only if the temperature during transit and storage was well controlled otherwise perforated PE was better.

Garden huckleberry

Solanaceae

Solanum intrusum Soria., synonymous with *S. scabrum* Mill., *S. nigrum* L. var. *guineense*. It is probably native to Africa but has been grown for its insipid fruits in Britain and America. It is similar to *S. nigrum*, the black nightshade, which may contain solanine alkaloids in poisonous quantities (Harrison *et al.* 1985). It was reported by (Purseglove 1975) to be widespread throughout the Old World tropics as a weed and occasionally cultivated as a pot herb in Africa and Asia but is reputed in Europe to be poisonous. It should not be confused with the Ericaceae plant *Vaccinium ovatum*, which is also called huckleberry.

Genips

Sapindaceae

Melicocca bijuga L. synonymous with *M. bijugatus* Jacq. and *M. carpopodea* Juss. Other common names include Spanish lime, Guinep, Genipe and Mamoncillo. It is native to northern South America and naturalized in coastal and dry forest regions in Central America, the Caribbean and Mexico. It is believed to have been introduced into the West Indies in pre-Columbian times and has also been introduced to parts of Africa and the Pacific. They are commonly sold at the roadside, particularly to children and the skin is easily cracked with the teeth to gain access to the pulp. The fruit are borne in clusters and are ovoid in shape and usually about 3 cm long. They have a hard green skin and inside a large ovoid stone surrounded by a thin layer of sweet acid yellow pulp (Figure 89).

Giant granadilla

Passifloraceae

Passiflora quadrangularis L., *Passiflora macrocarpa* M.T. Mast., also called granadilla. It is a native of tropical America and was reported to be growing in Barbados in 1750. It is commonly cultivated in Latin America from Mexico to Brazil and Peru. It was introduced into Malaya in the 18th century and it has



Figure 89 Genip fruit *Melicocca bijuga*.

Table 99 The composition of giant granadilla fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	72.93 g	Thiamine	0.000 mg
Energy	97 kcal	Riboflavin	0.130 mg
Protein	2.20 g	Niacin	1.500 mg
Total lipid (fat)	0.70 g	Vitamin B-6	0.100 mg
Carbohydrate, by difference	23.38 g	Folate	14 µg DFE
Total dietary fibre	10.4 g	Vitamin B-12	0.00 µg
Total sugars	11.20 g	Vitamin A	64 µg RAE
Calcium	12 mg	Vitamin A	1272 IU
Iron	1.60 mg	Vitamin E	0.02 mg
		(α-tocopherol)	
Magnesium	29 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	68 mg	Vitamin D	0 IU
Potassium	348 mg	Vitamin K	0.7 µg
		(phylloquinone)	
Sodium	28 mg	Fatty acids, total saturated	0.059 g
		Fatty acids, total monounsaturated	0.086 g
Zinc	0.10 mg	Fatty acids, total polyunsaturated	0.411 g
Total ascorbic acid	30.0 mg		

been distributed throughout south east Asia as well as the lowlands of India, Sri Lanka, the Philippines, tropical Africa and Queensland in Australia. It was being grown in Hawai'i in 1888 (Morton 1987). It is a fast growing vine up to 15 m long with fleshy roots that becomes enlarged with age. The flowers are solitary and fragrant up to 12 cm wide, have a bell-shaped calyx, with 5 white and pink petals up to 4.5 cm long (Morton 1987). The edible portion is the soft pulp around the seeds of the fruit, which is up to 30 cm long and 15 cm in diameter. The skin is soft and below this the flesh is white and juicy and up to 4 cm thick. The fruit is green as it matures and turns pale yellow or yellowish-green at maturity. The green fruit can be boiled and used as a vegetable. It produces tuberous roots, which Purseglove (1968) states, are usually considered poisonous, but are said to be eaten in Jamaica as a substitute for yams. The chemical content was given by USDA (2012) in Table 99.

Harvesting is carried out by hand when the skin becomes translucent and glossy and is beginning to turn yellowish at the apex. The fruits are clipped from the vine and are delicate and should be handled carefully (Morton 1987). Refrigerated storage recommendations include

- 10 °C for 17 days for green, turning and yellow fruits, immature fruit subsequently ripened normally at 21.1 °C (Wardlaw 1937);
- 7.2–10 °C for 15 days for green and turning fruit with subsequent normal ripening at 21.1 °C in 7–10 days, but fully yellow fruit were overripe after 7 days at 10 °C (Wardlaw 1937);
- 8.3 °C where mature fruits stored well over long periods, but immature fruits were unpalatable after storage (Wardlaw 1937);
- 7–10 °C and 85–90% r.h. for 3–5 weeks (Snowdon 1990);
- 10 °C and 85–90% r.h. for 21–28 days (SeaLand 1991).

Ginseng

Araliaceae

Panax spp. *P. ginseng* C.A Meyer (Korean ginseng), *P. quinquefolium* L. (American ginseng), *P. notoginseng* (Chinese ginseng or Sanch'i) and *P. japonica* (Japanese ginseng or Chikusetsu-ningin). Ginseng is primarily grown between 30 and 48° north latitude in Canada, China, Korea and the United States (Lee and Yun 2002). It is a perennial herbaceous plant; the edible portion is the main root with two to five lateral roots. The taste is aromatic, mucilaginous and sweet accompanied by some bitterness. It has been used for various medical purposes from ancient times in Korea and China.

Harvesting

Ginseng is usually harvested 3–5 years after transplanting 1-year-old seedlings. The optimum time for harvest is August to October in Korea, when their medicinal value is highest (Lee and Yun 2002).

Postharvest physiology

Ginseng roots produce only minute amounts of ethylene and are not sensitive to ethylene. The respiration rate of the harvested roots was greatly affected by temperature and was particularly high at 25 °C (Table 100).

Table 100 Respiration rate of ginseng roots (source: Lee and Kim 1979)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	5.5
10	15.0
15	33.0
25	95.0

Storage

At 25 °C roots were successfully stored for 20 days but at 0 °C and higher than 95% r.h. they can be stored for 2 months (Lee and Yun 2002). Storage at 0 °C in 1% O₂ combined with levels of CO₂ higher than 5% was recommended by Lee and Kim (1979) and Yun and Lee (1998). The formation of cavities within the root is a common problem caused by cultural conditions and catabolism of starch. Storage in CA attenuated cavitation and also reduced microorganism growth. Cavitation was significantly reduced during storage in 15% CO₂ compared to those stored in air (Lee and Yun 2002).

Diseases

Grey mould (*Botrytis cinerea*) was reported to be common postharvest disease with lesions frequently beginning in wounds and spreading to other areas of the roots. Storage at low temperatures or CA slowed the rate of development and the rate of spread of the disease (Lee and Yun 2002).

Gooseberry

Saxifragaceae, Grossulariaceae

Ribes nigrum L. *Ribes* spp. European gooseberries are *R. uva-crispa* L. synonymous with *R. grossulariodes* but cultivars grown in American are virtually all from crosses between *R. uva-crispa* and the American gooseberry *R. hirtellum* Michx. The European gooseberry produces much larger fruit than the American gooseberry. Gooseberry is small spiny bushes whose fruits are oval to round in shape and are borne singly or in clusters. They usually have a pale green skin,

Table 101 The composition of gooseberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.87 g	Total ascorbic acid	27.7 mg
Energy	44 kcal	Thiamine	0.040 mg
Protein	0.88 g	Riboflavin	0.030 mg
Total lipid (fat)	0.58 g	Niacin	0.300 mg
Carbohydrate, by difference	10.18 g	Vitamin B-6	0.080 mg
Total dietary fibre	4.3 g	Folate	6 µg DFE
Calcium	25 mg	Vitamin B-12	0.00 µg
Iron	0.31 mg	Vitamin A	15 µg RAE
Magnesium	10 mg	Vitamin A	290 IU
Phosphorus	27 mg	Vitamin E	0.37 mg
		(α-tocopherol)	
Potassium	198 mg	Fatty acids, total saturated	0.038 g
Sodium	1 mg	Fatty acids, total monounsaturated	0.051 g
Zinc	0.12 mg	Fatty acids, total polyunsaturated	0.317 g

sometimes with darker green 'veins' running lengthways. They may develop a brownish red colour when mature with soft fine hairs over the skin surface. However, they may be grey-green, yellow or shades of red from pink to purple to almost black. The skin is crisp and juicy and they have a soft acid pericarp with many small seeds. There are many cultivars for example the cultivar London dates back to the early 19th century and produces very large fruit. Other desert cultivars include Early Sulphur, Gage, Glencarse, Langley, Muscat, Warrington and Whitesmith. Cultivars more suitable for cooking include Careless, Lancer, Leveller and Whinham's Industry. The chemical content was given by USDA (2012) in Table 101.

Harvesting

This is done by hand with care since the bushes can be very thorny. Bushes should be pruned to keep them open, which not only facilitates harvesting but helps in the control of Mildew (*Sphaerotheca mors-uvae*). Harvest maturity for the desert cultivars is when the fruit become a lighter green or develop a reddish-brown colour. For cooking cultivars they are harvested when they reach an acceptable size. Some work has been done on mechanical harvesters, but it was found that

it was necessary to spray the bushes with a chemical to loosen the fruit before harvesting. Hitchcock (1973) showed the effectiveness of Ethrel treatment and the importance of concentration (Figure 14). In practical use the time between application of Ethrel and fruit fall was affected by fruit maturity and weather conditions. Ethrel can reduce the shelf life of fruits and is not allowed by some supermarkets (John Love 1994, personal communication quoted by Thompson 1996).

Precooling

Forced air cooling with high humidity was the most acceptable method, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling less suitable (MAFF n.d.).

Postharvest physiology

McKay and Van Eck (2006) found that fruit were sensitive to ethylene. They were shown to have a reduced respiration rate in low O₂ levels at temperatures between 0 and 20 °C (Table 102). This might indicate that storage could be improved under controlled atmosphere conditions. Hardenburg *et al.* (1990) gave their respiration rate in Table 103.

Table 102 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Leveller gooseberries (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	10	13	23	40	58
In 3% O ₂	7		16		26

Table 103 Respiration rate of gooseberry fruit at different temperatures (source: adapted from Hardenburg *et al.* 1990)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	6–8
4–5	8–16
10	12–34
15–16	30–74
20–21	46–116

Storage

The fruit will freeze at about -1.8 to -1.6°C (Wright 1942). Refrigerated storage recommendations include

- -0.5 to 0°C and 90–95% r.h. for 3–4 weeks with some losses mainly through collapsed berries, but they should be processed immediately after removal from storage (Hardenburg *et al.* 1990);
- -0.5 to 1°C and 90–95% r.h. for 2–4 weeks (Snowdon 1990);
- -0.5 and 90–95% r.h. for 14–28 days (SeaLand 1991);
- 0 – 1°C for up to 3 weeks (Batzner and Helm 1999).

Controlled atmosphere storage

Harb and Streif (2004a) stored the cultivar Achilles at 1°C in air, 6% CO_2 + 18% O_2 , 6% CO_2 + 18% O_2 , 12% CO_2 + 18% O_2 , 18% CO_2 + 18% O_2 , 12% CO_2 + 2% O_2 , 18% CO_2 + 2% O_2 or 24% CO_2 + 2% O_2 . Storage in air led to a reduction in firmness, darkening of fruit colour, mealy texture and lower acidity level compared to CA storage. Storage in 2% O_2 + 18% CO_2 resulted in off-flavours, but in 12% CO_2 + 2% O_2 no off-flavour was detected. They recommended 12–15% CO_2 + 18% O_2 for up to 7 weeks. Certain cultivars of gooseberries have been held for as long as 3 months at 0°C in air (McKay and Van Eck 2006) but for even longer storage they suggested harvesting at the green mature stage and placing them at -0.5 to -0.9°C with 93% r.h. in 2.5–3.0% O_2 + 20–25% CO_2 .

Diseases

The main postharvest disease is grey mould (*Botrytis cinerea*) which can appear as small brown spots on fruit that enlarge rapidly at temperatures above 10°C and gradually affected the entire berry with a soft rot. They can be susceptible to American powdery mildew (*Sphaerotheca mors-uva*) and fruit can become contaminated by soil splash after heavy rain leading to infection with *Mucor piriformis* (Dennis 1983). He also reported a fruit disease in gooseberry caused by *Alternaria* and *Stemphyllum* where the infection was usually confined to the seeds enclosed in the pericarp. However, if fruit were stored for a few days at ambient temperature the fungus invaded the pericarp tissue.

Governor's plum

Flacourtiaceae

Flacourtia indica (Burm. f.) Merr. also called ciruela forastera. See also Lovi Lovi (*Flacourtia inermis* Roxb.). It was reported to be a native of tropical Africa and Asia. It is a moderate size tree growing in Sri Lanka where it is used as an ornamental plant, but its fruit is edible and very popular (Amarasinghe and Jayasinghe 2006). The fruits can be eaten fresh or made into jam. It is a shrub or small tree sometimes with sharp stout thorns. The subglobose fruits are up to 3 cm in diameter, reddish purple to blackish in colour. The fruit is a pome with red skin ripening to purple. The pericarp is reddish, yellow or white in colour and is sweet with an acidic tang, juicy and contains 6–10 seeds in layered carpels (Kennard and Winters 1960). The leaves, roots and bark are used in herbal medicine for the treatment of coughs, pneumonia, bacterial throat infection, diarrhoea and arthritis. Amarasinghe and Jayasinghe (2006) investigated the fruit juice of *F. indica* and found flacourside (6-*O*-(*E*)-*p*-coumaroyl glucoside) together with the previously reported methyl 6-*O*-(*E*)-*p*-coumaroylglucopyranoside and 6-*O*-(*E*)-*p*-coumaroylglucopyranose.

Green gages

Rosaceae

Prunus domestica subsp. *italica* (Borkh.) Gams ex Hegi, synonymous with *P. insititia* and *P. italica*, they are also simply called gages. It is found in the wild in Asia Minor and was originally cultivated in France where it was called Reine Claude in honour of the Duchess of Brittany (1499–1524) and they are also called la bonne reine after the same lady. They were brought to Britain early in the 18th century either by the botanist Sir William Gage or by the Rev. John Gage. It is a sturdy, rarely thorny, shrub or small tree. The fruit are drupes that are round, deeply sutured, often with red spots or russet with a slight bloom and firm green flesh. Since it is a subspecies of the European plum (*P. domestica* L.) it is probably also climacteric but no direct evidence could be found to confirm this. They are mature when the skin has turned from dark green to a light green or a yellowish

green. They also feel soft to the touch and have a distinct aroma at this time. One refrigerated storage recommendation was 0 °C for 3–6 weeks and then 6–8 °C for 6 weeks in Australia for Golden Gage (Fidler 1963).

Grapes

Vitaceae, Vitidaceae

Vitis spp. The genus *Vitis* contains some 60 inter-fertile wild species. Most grapes that are grown commercially are the hermaphrodite European grape (*V. vinifera* L.) but the monoecious American species, including *V. labrusca* L. (Fox Grape), *V. rupestris* Scheele (Sand Grape), *V. rotundifolia* Michx. (Muscadine grapes), *V. berlandieri* Planch and hybrids, are also important. Juice, wine and table cultivars have been developed from *V. labrusca* (Perkins-Veazie 2002b). Grapes may be classified in terms of their use since they are eaten fresh (table grapes), fermented into wines, fortified wines, liqueurs and spirits (wine grapes) and dried into sultanas, raisins and currents. There are several hundred varieties and cultivars that have been selected for these different uses. For wine perhaps the most common are selections of Chardonnay or Pineau Blanc, Pineau Noir, Cabernet and Riesling. Some cultivars have been selected for production in tropical climates for example Barbara and Bangalore Blue. Jackson and Looney (1999) reported that the main types used for dried fruit are all *V. vinifera* with the small seedless Zante (Black Corinth) and Australian Carina mainly used for currants, Thompson Seedless and Sultana mainly used for sultanas and Thompson Seedless and Muscat mainly used for raisins. Most harvesting and handling practices are the same for fruit of all the species, although they can vary depending on what the fruit will be used for, but this chapter deals with grapes for the fresh market.

V. vinifera probably originated in an area between the Black Sea and Iran and archaeologists have speculated that they have been cultivated for 7000–8000 years (Zohary 2004). There are eight specific references to grapes in the Old Testament of the Christian Bible. For example in Leviticus 19: 10 'And thou shalt not glean thy vineyard ...', also in Moses' song 'and thou didst drink the pure blood of the grape.' (Deuteronomy 32: 14). Terral *et al.* (2010) gave an

Table 104 World production of grapes (source: adapted from FAO 2013)

	2011	2010	2009	2008	2007	2006	2005
Area harvested (million hectares)	7.1	7.2	7.5	7.2	7.3	7.4	7.4
Production (million tonnes)	69.5	68.3	67.9	67.4	65.5	67.3	67.4

excellent introduction to the history and distribution of *Vitis*. From its origin grape cultivation seems to have spread gradually westwards. In Greece and Crete, the cultivation would have started during the fifth millennium BCE. (Valamoti *et al.* 2007) probably the 9th century BCE. in Italy (di Vora and Castelletti 1995), in Spain the first part of the last millennium BCE. (Rivera Nuñez and Walker 1989, Buxo 2008) and in France about 600 BCE. (Brun and Laubheimer 2001). Total world production in 2010 was estimated by FAO (2013) as 67,116,255 tonnes.

Grape vines occupy more land in the world than any other single fruit and account for almost half of the total world production of all fruits. The area of production and production quantities have remained relatively stable (Table 104) and of this some 71% of world grape production is used for wine, 27% as fresh fruit and 2% as dried fruit.

It is a deciduous woody vine. The fruit is a berry borne in racemes, commonly called bunches, and they are not climacteric. Each berry is produced from a single ovary that produces two seeds. Through selection and breeding some cultivars do not produce seeds because of ovule abortion. The flowers are borne on a rachis that is the axis of the inflorescence. The raceme is attached to the vine by a peduncle that is branched into several pedicels each of which ends in a berry. The berry has a central vascular bundle surrounded by the mesocarp, commonly called the flesh, containing the seeds or aborted ovules that are contained within the exocarp commonly called the skin (Figure 90).

The exocarp (skin) is 6–10 cells thick and is coated with a cuticle on the outside and between the skin and the pulp is a peripheral layer of vascular tissue. Just under the outer layer of skin cells lies a tightly packed layer of flattened cells called the hypodermis. Many types of tannins are concentrated in these cells, which strongly influence astringency and flavour.

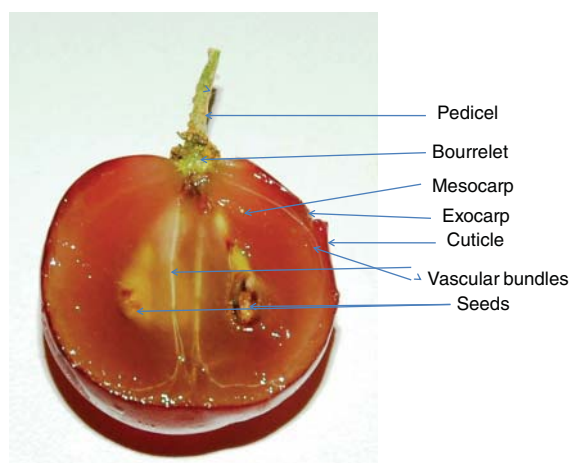


Figure 90 Section through a grape fruit. (Photo: Caitlin Thompson.)
See colour plate section.

Most of these compounds are accumulated prior to *véraison*. The cells that make up the mesocarp are typically larger and rounder than those in the exocarp. These cells contain large vacuoles, which are the primary sites for the accumulation of sugars during ripening. Sucrose that is transported from the vine leaves is mainly broken down into glucose and fructose. Acids and phenolic compounds are also concentrated in these vacuoles. Vacuoles expand or contract substantially in response to water uptake or loss, particularly after *véraison*.

During the period from flowering to maturity there was an increase of waxy deposits and significant modifications of the wax surface morphology on the skin of the fruit. This layer contains cutin, which is a fatty substance formed from mixtures of complex derivatives of fatty acids. It impregnates the outer wall of the epidermis forming a separate layer. The content of cutin per unit surface decreased more than 2.5-fold between berry set, 16 days after anthesis, and *véraison* and might predispose the berries to fungal infection (Comménil *et al.* 1997). The cuticle consists of a structural component, the cutin layer, formed from hydroxy-fatty acid esters, intracuticular waxes and a thin amorphous epicuticular wax layer consisting of a very complex mixture of long chain lipids. The components include the cyclic terpenoid oleanolic acid consisting of some 30% and soft wax composed chiefly of long-chain alcohols together with smaller amounts of aldehydes, esters, fatty acids,

hydrocarbons, oleanolic acid and small amounts of high-molecular-weight substances (Radler and Horn, 1965). The greyish, powdery film that occurs naturally on grapes contains wild yeast and dust as well as cutin. The exocarp does not contain a significant number of functional stomata. Therefore water loss occurs mostly through the waxy cuticle, which in turn restricts water loss. Consequently the berries are not well able to shed excess water quickly, which makes them more susceptible to splitting than other fruits. Another consequence is that they do not dissipate heat well via water evaporation.

Berries develop after pollination with an initial rapid cell division and high respiration rate followed by a period of cell enlargement. There is then a period of slow growth and respiration rate during which the embryo reaches maturity, acidity reaches its peak and chlorophyll begins to be broken down. The final phase is called the *véraison* and is characterized by a decrease in acidity, chlorophyll and respiration rate and an increase in size, sugars, amino acids and synthesis of anthocyanins in coloured varieties. Fruit development lasts for 100–120 days and has been classified into three phases (Zoffoli and Latorre 2011):

1. Berries develop after pollination with an initial rapid cell division and high respiration rate followed by a period of cell enlargement. This phase takes some 40 days starting at fruit set with anticlinal and periclinal cell division. Chlorophyll content increases and it was reported that there was an increase in malic acid to 69% of the level at maturity and an increase to 92% of the level at maturity in tartaric acid. Seeds reach their full size at the end of this phase.
2. There is then a period of slow growth and slowing respiration rate during which the embryo reaches maturity, acidity reaches its peak and chlorophyll begins to be broken down. There is synthesis and a high concentration of the plant growth substances indole acetic acid, gibberellic acid and cytokinin.
3. The final phase is called the *véraison* and is characterized by a decrease in acidity (malic decreases and tartaric remains stable), chlorophyll content and respiration rate and an increase in size, sugars, amino acids and synthesis of anthocyanins in coloured cultivars. During the *véraison* their titratable acidity decreased from 2.0 to 1.5% in

Thompson Seedless and from 0.7 to 0.5% in Red Globe (Chervin *et al.* 2012). Within a 10-day period sugar content increased by a factor of 6 or 7 (Hulme 1971). Indole acetic acid, gibberellic acid and cytokinin remained low but there was an increase in abscisic acid at the beginning of the véraison.

The flavour of American species has been described as 'foxy' and 'musky' and are generally considered to have an inferior flavour to *V. vinifera*. *V. vinifera* production was decimated in Europe in the mid-19th century because the aphid *Phylloxera vastatrix* (*Daktulosphaira vitifoliae*) had been introduced accidentally from the United States and was reported in Britain and France in 1863 and in South Africa, Australia and Algeria by 1885. *P. vastatrix* infests roots and some indigenous American species are resistant; therefore these American species can be used as rootstocks for *V. vinifera* in order to control the aphids.

Grapes have a relatively low vitamin C content of about 4 mg 100 g⁻¹ and malic and tartaric constitute over 90% of the acidity of the fruit. They have high levels of sugar with glucose being the predominant sugar in unripe grapes where it can account for 85% of the total sugar, so much so that glucose was referred to as *grape sugar* in older literature. In ripe fruit fructose usually slightly exceeds glucose (Burton 1982). USDA (2006a, 2006b) gave the following data for 'American type (slip skin)' grapes of 17.15% carbohydrate by difference and 16.25% total sugars. For red or green 'European type varieties, such as, Thompson Seedless' they gave 18.10% carbohydrate by difference and 15.48% total sugars. 'Carbohydrate by difference' is determined by subtracting the sum of ash, moisture, fat and protein from 100. Grapes also contain high levels of polyphenols but they are mainly in the skin and the seeds (Teissedre and Chervin 2011). Grape skins contain significant amounts of flavonoids as well as other polyphenols and the amount of phenolic antioxidants from 150 g of the cultivar Napoleon was 150 mg with seeds and peel and 5 mg without seeds and peel (Tomás-Barberán and Gil 2008). The proanthocyanidin extract of grape seeds, recovered from the pulpy waste of the wine industry, is used in treatment of cancer and cardiovascular diseases. Kanner *et al.* (1994) showed that the black seedless grapes and Cabernet Sauvignon and Petite Sirah red

wines contained high concentrations of phenolics: 920, 1800 and 3200 mg L⁻¹, respectively, while green Thompson Seedless grapes contain only 260 mg kg⁻¹ phenolics. Stilbene resveratrol is a non-flavonoid polyphenolic that is present in grapes and has been demonstrated to help prevent cancer and cardiovascular diseases (Cantos *et al.* 2000). Teissedre and Chervin (2011) in a review reported that frequent and moderate consumption of grapes could contribute to disease prevention, particularly from the phenolic compounds. However, consumption of large amounts of sugar has been associated with negative effects on health and grapes have high levels of sugar.

Storage at 0 °C induced an accumulation of anthocyanin in the skin of grapes (Romero *et al.* 2008) and Tomás-Barberán and Espin (2001) found an increase in the anthocyanin content of grapes and some other fruits during cold storage. However, anthocyanin levels in grapes were lower after storage at 0 °C for those that had been stored for 3 days in controlled atmosphere storage of 20% CO₂ +20% O₂ compared to those that had not been placed directly into air (Romero *et al.* 2008). They also found that storage of grapes in 20% CO₂ retained their quality and had less decay in during storage at 0 °C than those in air. Artés-Hernández *et al.* (2006) stored the cultivar Superior Seedless grapes in modified atmosphere packaging for 7 days at 0 °C, 4 days at 8 °C and then 2 days at 20 °C. They found no changes in the phenolics during storage at 0 and 8 °C, but a slight decrease during the 2 days at 20 °C. Cantos *et al.* (2000) showed that ultraviolet light-C radiation could increase the phenolic stilbenes, mainly resveratrol, in grapes.

Preharvest factors

Fertilizers

As with all crops the conditions in which they have been grown and their stage of maturity at harvest can affect their quality and often their postharvest characteristics. For example Choudhury *et al.* (1999) found that bunches of Italia grapes from vines that had been grown with 35% nitrogen as urea and 65% as calcium nitrate through fertigation had less water loss and less decay after 56 days of storage at 2–4 °C and 90–95% r.h. than bunches from treatments that had higher levels of nitrogen. Massignan *et al.* (1999) grew Italia grapes both conventionally and organically and after storage at 0 °C and 90–95% r.h. for 30 days

they found that organically grown grapes were more prone to storage decay than those grown conventionally. Cefola *et al.* (2011) reported that at harvest, grapevines that had been grown without soil (hydroponically) produced berries that were 30% firmer than those grown in soil. They also had 60% higher antioxidant activity and total phenol content than fruit harvested from vines grown in soil.

Cytokinin

Rachis browning can occur postharvest and Balic *et al.* (2012) studied the effects of various postharvest treatments and found a genetic relationship with this disorder. They suggested a putative cellular regulatory mechanism of water loss and senescence in the rachis that most likely involved ethylene and oxidative stress metabolism. They found that cytokinin applied to the fruit 1 day before harvest lowered percentage rachis browning after 90 days at 0 °C plus 2 days at 20 °C compared to those not treated.

Calcium

Grey mould is a major postharvest disease of grapes and preharvest treatment can contribute to its control. Chervin *et al.* (2009) reported that preharvest applications of a solution containing 1% calcium chloride and 16% ethanol reduced rotting in the cultivar Chasselas picked at a late harvest date. They found that clusters that were not treated had some 15% grey mould while treated fruit had about 5%. And this effect persisted during a 6-week cold storage period. The treatments did not affect the sensory analysis of healthy berries.

Gibberellic acid

Gibberellic acid (GA₃) can be sprayed on vines to increase berry size and bunch shape. Zoffoli *et al.* (2009) found that because berry size is the main quality factor in international markets, farmers often over use it in an effort to increase berry size. The over use of GA₃, eight instead of two GA₃ applications on Thompson Seedless, and one GA₃ application on Redglobe and Ruby Seedless, increased berry pedicel thickness and lowered cuticle content but induced shatter and predisposed grapes to grey mould. Raban *et al.* (2013) treated the cultivars Mystery, Superior and Crimson with gibberellin, cytokinin or both at berry diameter of 6–8 mm. The fruits were harvested at commercial maturity and stored for 7 days shelf

life either immediately after harvest or after 2 weeks storage at 0 °C. Fruits treated with the combination of GA and cytokinin had increased berry weight and diameter, and rachis diameter in all three cultivars, but had minor or no effect on TSS and acidity. Rachis browning was lower after storage for Mystery treated with GA, while the other cultivars showed no difference between those treated with GA and cytokinin and the rachis of those not treated.

Harvest maturity

Grapes are non-climacteric fruit and therefore it is important in terms of quality to determine accurately the optimum harvest maturity. Coombe (1992) found that individual fruit in a bunch do not all mature at the same time, which can affect harvest maturity assessments. Peak maturity is judged on peel colour, pulp texture, aroma, flavour and sweetness. The time between flowering and harvesting can also be used in conjunction with these measurements. For example in India the cultivar Gulabi exhibited a double sigmoid pattern of growth and took 12 weeks from fruit set to harvest maturity (Rao *et al.* 1995). The total soluble solids content can be used to determine harvest maturity usually a TSS of 14–17.5% is recommended. However, optimum TSS varies between cultivars for example it should be 18–20% for Thompson Seedless and 12–14% for Bangalore Blue (Pantastico 1975). For Muscadine grapes optimum harvest maturity is when the TSS is between 14 and 18% (Ballinger and McClure 1983). Also for American species it was recommended that they should be harvested when the TSS is 14–18% (Perkins-Veazie 2002b). The ratio between TSS and TA is also used. For coloured varieties, there may also be a minimum colour requirement in some production areas. If the berries easily separate from the fruit stalk they are fully mature and Ballinger and McClure (1983) recommended the ease of detachment of the berries in combination with TSS. However, this can be a problem when they are harvested for the fresh market since the market requires them to be attached to the bunch and many berries may fall off during handling. They are also more susceptible to decay at this stage (Anonymous 1968). Witbooi *et al.* (2000) found that an increase in harvest maturity was associated with increased susceptibility to *Aspergillus niger* and *Rhizopus stolonifer* infection during subsequent storage.

Table 105 Changing in physical and chemical constituents of *V. rotundifolia* cultivar Noble grapes during maturation (source: adapted from Carroll and Marcy 1982)

	Sampling day						
	0	21	36	47	54	62	72
Berry weight (g)	1.52	1.29	2.44	3.40	3.86	4.12	3.81
Berry diameter (cm)	1.40	1.45	1.60	1.70	1.65	1.75	1.75
Acidity	28.4	27.1	14.7	10.0	7.8	6.6	6.7
Total soluble solids	3.6	4.3	9.8	12.1	12.7	12.1	15.7
Total phenol	2.01	2.14	1.78	1.92	2.78	2.45	3.12
Moisture content	92.4	91.9	89.2	86.8	85.3	83.8	82.7

Crop load, canopy density, soil moisture availability and nutrition to the vine can result in variation in ripening of clusters on different vines in the same field. Variation in the ripening of different clusters on the same vine is due to time differences in budbreak, emergence and development of different panicles. The clusters at the periphery of a vine canopy are usually riper than those near the trunk and the clusters on a vine with less crop load are riper than those on a vine with heavy crop load. There is also variation in the ripening of berries within a cluster, which is attributed to difference in the anthesis of flowers and fruit setting. The anthesis and fruit set is in acropetal succession in grape, the berries at the base of the cluster are set first and ripen first followed in succession by the ones at the middle and finally at the tip (Chadha and Shikhamany 1999). The changes in characteristics of *V. rotundifolia* during maturation on the vine are given in Table 105.

Harvesting and packing

Crisosto and Smilanick (2002) reported that most California table grapes are packed in the field in contrast to South Africa and Chile where they are more commonly packed in packhouses. The most common field-packing system is the 'avenue pack'. The fruit are picked and placed into picking boxes, which are then transferred a short distance to the packer, who works at a small and shape portable stand in the avenue between vineyard blocks. Fruit packed in packhouses are harvested and placed in field boxes

without trimming and placed in the shade of the vines to await transport to the packhouse. At the packhouse packers select, trim and pack the fruit often into two different grades simultaneously. In some operations, trimming, colour sorting and a first quality sorting may be done in the field. In all of the systems, grapes are nearly always packed on a scale to facilitate packing to a precise net weight, whether packed in the field or a packhouses. In general mid and late season grapes are packed in plastic bags or wrapped in paper. For early season grapes, bulk pack is mainly used. In all cases, the packed fruit are subject to quality inspection and check weighing. After packing the boxes are palletized, and often loaded pallets pass through a device that straightens and tightens the stacks of containers. These pallet loads are unitized, usually by strapping or netting.

Zoffoli and Latorre (2011) described the packaging operations in Chile, which were similar to those described earlier for California. Field packing is where the fruit are harvested directly into the boxes used for marketing. They commented that this method has reduced water loss and bruising presumably by the lower amount of handling the grapes. Transporting the grapes to packhouses in plastic field boxes is done with relatively large volumes where the temperature is controlled. The fruit are placed on a conveyor belt and workers select and trim the clusters that are then passed to others who pack them into the shipping boxes. These are designed to fit the standard 1200 × 1000 mm pallet using boxes that are 40 × 30, 50 × 30 or 60 × 40 and 10–13 cm high, packing to a maximum height of 1.8 m with between 72 and 96 boxes per pallet.

Because of the high ambient temperature in Eritrea harvesting is carried out during the early hours of the day before the berry temperature rises above 20 °C. Harvesting is by hand with the workers experienced in selecting bunches at the desired stage of maturity and placing them carefully in plastic boxes (Figure 91). When a box is full it is taken to the side of the field where it is loaded onto a trailer (Figure 92). When the trailer is full it is taken to the packhouse situated at most 200 or 300 m from the field. This method results in only a short delay between harvesting and arrival in the packhouse.

Grapes for processing may be harvested by tractor-mounted machines which have combing fingers that are run up the stems pulling off the fruit



Figure 91 Harvesting grapes at Hagaz in Eritrea. (Photo: D. Okubamicael Haile.) See colour plate section.



Figure 92 Grape harvesting in Hagaz in Eritrea loading plastic boxes containing the fruit onto a trailer for transport to the packhouse. (Photo: D. Okubamicael Haile.) See colour plate section.

bunches, as well as a high proportion of the leaves. The fruit are removed from the plants by small amplitude high-frequency vibration by the rubber fingers being mounted on a vertical drum that rotates at the same velocity as the harvester moves forward. The fruit may subsequently be separated from the leaves by blowers and the juice extracted. In other cases the fruit is taken straight from the field and passed through a press and filter system or to be dried into currents or raisins. It is important with mechanical harvesting is to use cultivars whose fruit all mature at the same time and to prune the vines to facilitate harvesting (Cargill and Booster 1983). Chen *et al.* (1990) described the design, construction and testing of a small harvester suitable for harvesting muscadine grapes in medium and small vineyards that had a harvesting rate of 0.28 ha h^{-1} .

Precooling

For the fresh market precooling the grapes should be carried out as quickly as possible after harvest. Crisosto and Dokoozlian (2001) reported that a short delay at high air temperatures before precooling contributed to stem browning. In California many growers use forced-air coolers on boxes of fruit packed onto pallets. They are designed to achieve $7/8$ cooling in 6 h or less. After cooling is completed, the pallets are moved to a cold store to await transport. Zoffoli and Latorre (2011) also reported that packed fruit should be cooled within 6 h of harvest and that a system that and air flow of $0.001\text{--}0.002 \text{ m}^{-3} \text{ s}^{-1} \text{ kg}^{-1}$ was suitable for packed grapes. They also found that forced-air cooling reduced the fruit temperature from 25 to 30°C to between 0 and 4°C in less than 12 h for 32 tonnes of packed grapes. Elansari *et al.* (2000) described a wet deck pre-cooling system based on an ice bank used in the field for grapes prior to loading into the cold store. The bank of ice was built up over-night using the mains electricity and the water pump and air circulation fans are driven from the engine of the tractor in the field. Aswaney (2007) compared different precooling methods and reported that forced-air cooling or pressure cooling was ideal for small, delicate products such as grapes that cannot be handled in bulk and that are packed in cardboard cartons before precooling. In India, this is the method that has been most commonly used for precooling grapes for the export market. He described the methods in detail including the need for definite stacking patterns and baffling of stacks so that cooling air is forced through, rather than around individual cartons. Cartons have ventilation holes in the direction air will move and a minimum of packing materials that would interfere with free air movement through the containers. With well-designed cartons a relatively small pressure differential between the two sides of the container results in good air movement and excellent heat transfer. Well managed forced-air cooling can result in rapid product movement through the cooling plant and the size of the plant is typically $1/3$ to $1/4$ that of an equivalent cold room type since cooling time is typically 10–25% of the time needed for conventional room cooling. Methods that can be used to improve the efficiency of precooling include sealing air leakage areas to forcing additional air through products, improving carton-stacking configurations

or orientation, modifying pallet-tunnel length and width and proper temperature monitoring. Carton design must allow a minimum of 5% sidewall ventilation and should be designed to allow ample airflow when the cartons are palletized (Aswaney 2007).

Ben Arie (1996) discussed the difficulties in pre-cooling fruit in modified atmosphere packaging. The solution involved whole pallet loads of half a tonne of fruit in cartons being wrapped in PE film after precooling. He found another advantage compared to individual cartons being lined with PE film that was that any condensation remained on the outside of the box and not on the fruit. Zoffoli and Latorre (2011) also mentioned the challenges of condensation associated with precooling and recommended storing the trimmed and packed fruit at 15 °C and 90% r.h., provided by an evaporative cooling system, for a period before cooling to 0 °C.

Prestorage treatment

Exposure of harvested plant material to 1-MCP has been shown to reduce their ethylene production. The cultivar Aleatico picked at 20.4–20.6 °Brix were left non-treated or treated with 1 mg L⁻¹ 1-MCP for 15 h at 20 °C and 95–100% r.h. then stored at 20 °C and 85% r.h. for 13 days. 1-MCP-treated grapes did not show ethylene production for 2 days after treatment, whereas non-treated grapes produced constant amounts of 3–4 µL kg⁻¹ h⁻¹ but after 6 days no significant differences was observed among samples or in their respiration rates. 1-MCP-treated grapes showed a significant loss of terpenols and esters, although levels of alcohols were maintained, especially hexan-1-ol. Levels of Grey mould were also higher in 1-MCP-treated fruit (Bellincontro *et al.* 2006). Pastor *et al.* (2011) used hydroxypropylmethylcellulose coatings on Muscatel grapes and found that they improved their overall quality during cold storage. Fruit that had been coated had slower weight losses and lower respiration rate and after 10 days of storage, coated samples had better microbial safety than uncoated samples.

Postharvest physiology

Crisosto and Smilanick (2002) reported that the stem respiration rate is approximately 15 times higher than that of the berries. They gave the respiration rates of

harvested fruit of *V. vinifera* as 1–2 ml CO₂ kg⁻¹ h⁻¹ at 0 °C, 3–4 at 5 °C, 5–8 at 10 °C and 12–15 at 20 °C. Hulme (1971) also reported a high increase in respiration rate with increasing temperatures over the range 0–37 °C and also a change in respiratory quotient of 0.70 at 10 °C, 0.96 at 20 °C, 1.32 at 30 °C and 1.44 at 37 °C. For Muscatine grapes the respiration rate was 6–14 at 2 °C, 8–18 at 5 °C and 33–68 mg kg⁻¹ h⁻¹ at 20 °C (Perkins-Veazie 2002b). Hulme respiration rate for *V. labrusca* was 3 at 0 °C, 5 at 4–5 °C, 8 at 10 °C, 16 at 15–16 °C, 33 at 20–21 °C and 39 at mg kg⁻¹ h⁻¹ at 25–27 °C (Lutz 1939, Perkins-Veazie 2002b).

At 20 °C the rate of ethylene production was less than 0.1 ml kg⁻¹ h⁻¹. Grapes are reported to be not very sensitive to ethylene, but exposure to levels greater than 10 ppm may be a secondary factor in the physiological disorder shatter (UC Davis n.d.). Grapes showed no response to exposure to 100 µL L⁻¹ of ethylene for 24 h at any temperature over the range of 5–35 °C (Inaba *et al.* 1989). However, ethylene in storage was found to induce abscission layer formation by Xu *et al.* (1999) and thus increase shatter. Ethylene can affect the physiological processes during maturation. In the cultivar Cabernet Sauvignon Chervin *et al.* (2008) found that only 73 of 14,562 genes of microarray slides were significantly modulated by exposure to 4 µL L⁻¹ ethylene for 24 h applied to fruit on the vines 8 weeks after flowering. They also found that ethylene application at véraison led to a berry diameter increase mainly because of sap intake and cell wall modifications, enabling cell elongation. They concluded that ethylene stimulated the accumulation of most gene transcripts in 1 h, also this stimulation may last for 24 h in some cases and occur in several parts of the berry. Ethylene production from Muscadine grapes and *V. labrusca* was less than 0.1 µL kg⁻¹ h⁻¹ (Lutz 1939, Perkins-Veazie 2002b). Pastor *et al.* (2011) found that throughout storage, total soluble solid contents sharply increased from 7 days onwards and phenol contents decreased, especially during the first 5 days.

Storage

Water loss is a major limiting factor in storage. Losses of only 1–2% can result in browning of the fruit stalk. This browning is often used by buyers as a good indicator of the fruits previous storage. With losses of

3–5% the fruit lose their bright turgid appearance. During storage of the cultivar Muscat of Alexandria at 6 °C where the temperature fluctuated from the average by ± 5 , ± 3 or ± 1 °C every 12 or 6 h, Ito and Nakamura (1985) found that the fluctuating temperatures were similar in condition to those stored at the constant temperature of 6 °C. Shelf life at 20 °C was about a week (Mercantilia 1989). Refrigerated storage recommendations include

- –2.2 to 0.6 °C and 80–85% r.h. for 2 weeks to 6 months depending on variety (Wardlaw 1937);
- –0.6 to 0 °C and 85–90% r.h. for 4 weeks (Phillips and Armstrong 1967);
- –1 to 0 °C and 85–90% r.h. for 3–4 weeks (Concord type) (Anonymous 1967);
- –0.6 to 0 °C and 85% r.h. for 4–8 weeks (Lutz and Hardenburg 1968);
- –0.6 to 0 °C and 85% r.h. for 3–5 weeks for Warden, 3–6 weeks for Niagara and Moore, 4–7 weeks for Concord and Delaware and 5–8 weeks for Catawba (Anonymous 1968);
- 1 °C and 85–95% r.h. (Hulme 1971);
- –2.2 to 1.7 °C (Anonymous 1968);
- 0 °C and 90–95% r.h. (Mercantilia 1989);
- 2 °C for 140 days (Mercantilia 1989);
- 4 °C for 90 days (Mercantilia 1989);
- 8 °C for 45 days (Mercantilia 1989);
- 12 °C for 25 days (Mercantilia 1989);
- –1 to –0.5 °C and 90–95% r.h. (Hardenburg *et al.* 1990);
- –1.1 °C and 90–95% r.h. for 56–180 days (SeaLand 1991);
- –1 to 0 °C and 90–95% r.h. and an airflow of 20–40 foot³ min^{–1} tonne^{–1} of grapes (Crisosto and Smilanick 2002);
- –0.5 to 0 °C and 95% r.h. and an airflow of 20–40 foot³ min^{–1} tonne^{–1} of grapes (Zoffoli and Latorre 2011).

Muscadine grapes (*V. rotundifolia* Michx.) can be held at –0.5 to 0 °C with greater than 90% r.h. for 1–4 weeks. Temperatures of 20 °C for 2 days after any cold storage interval shortened their subsequent shelf life to less than 1 week (Ballinger and McClure 1983). American grapes, *V. vinifera*, can be held at –0.5 to 0 °C with 85–90% r.h. for 4–7 weeks (Ginsburg *et al.* 1978).

Controlled atmosphere storage

Optimum CA storage recommendations were given as 1–3% CO₂ + 3–5% O₂ by SeaLand (1991). In storage trials at 0 °C the best treatment was 1.8% O₂ + 12% CO₂. After 46 days of storage in these conditions 97% of the berries were rated as having very good quality (UC Davis n.d.). The cultivars Waltham Cross and Barlinka were stored in controlled atmosphere storage at –0.5 °C for 4 weeks. The percentage of loose berries in Waltham Cross was higher (>5%) in 21% O₂ + 5% CO₂ than in lower O₂ levels (Laszlo 1985). Crisosto and Smilanick (2002) reported that 2–5% O₂ + 1–5% CO₂ during storage or shipment was not recommended because it was only slightly beneficial, but CO₂ at 10–15% in air can be used to control grey mould for 2–4 weeks depending on the cultivar. Preliminary data indicate that 'Fry' Muscadine grapes had reduced decay when held in 10% O₂ + 10–15% CO₂ (Perkins-Veazie 2002b).

Crisosto *et al.* (2003a, 2003b) studied 5, 10, 15, 20 and 25% CO₂ factorially combined with 3, 6 and 12% O₂ on Redglobe. Optimum conditions for late harvested fruit (19% TSS) were 10% CO₂ + 3, 6 or 12% O₂ for up to 12 weeks storage and for early harvested fruit (16.5% total soluble solids) it was 10% CO₂ + 6% O₂ for up to 4 weeks. Pedicel browning was accelerated in grapes exposed to 10% CO₂ for early harvested and above 15% for late harvested fruit. However, the same authors (Crisosto *et al.* 2003a) found that the combination of 15% CO₂ with 3, 6 or 12% O₂ was optimum for late harvested Thompson Seedless for up to 12 weeks and Controlled atmosphere storage should not be used for early commercially harvested grapes.

There is some indication that controlled atmosphere storage can affect flavour development in grapes. Dourtoglou *et al.* (1994) found fruit exposed to 100% CO₂ for 20 h before storage developed 114 volatile compounds in storage at 0 °C compared to only 60 in those that had not. Alcoholic flavour can also be affected by controlled atmosphere storage. Karaoulanis (1968) showed that grapes stored in 12% CO₂ + 21% O₂ + 67% N₂ for 30 days had only 17 mg 100 g^{–1} fresh weight alcohol while those stored in 25% CO₂ + 21% O₂ + 54% N₂ had 170 mg 100 g^{–1} at the same time. The cultivar Kyoho stored well in 4% O₂ + 30% CO₂ but an alcoholic flavour and browning occurred after 45 days. Storage in 4% O₂ + 9% CO₂ or 80% O₂ + 20% N₂ retained good quality during

60 days of storage without off-flavours (Deng *et al.* 2006).

Magomedov (1987) showed that different cultivars required different controlled atmosphere storage conditions. The cultivars Agadai and Dol'chatyi stored best in 3% CO₂ + 5% O₂ whereas for Muskat Derbentskii 5% CO₂ + 5% O₂ or 3% CO₂ + 2% O₂ were more suitable. Muskat Derbentskii, Dol'chatyi and Agadai had a storage life of up to 7, 6 and 5 months, respectively, in controlled atmosphere storage. The best results for storage of the cultivar Moldova were in 8% CO₂ + 2–3% O₂ or 10% CO₂ + 2–3% O₂. In these conditions, 89, 80 and 75% of first grade grapes were obtained after 5, 6½ and 7½ months of storage, respectively. In another trial with Muscat of Hamburg and Italia, grapes stored in air or in controlled atmosphere storage for 3–7 months were assessed in relation to profitability. The best results were again obtained in storage of 8% CO₂ + 2–3% O₂ for Muscat of Hamburg and 5% CO₂ + 2–3% O₂ for Italia (Khitron and Lyublinskaya 1991). Turbin and Voloshin (1984) showed that for storage for less than 5 months, 8% CO₂ + 3–5% O₂ was most suitable for Muskat Gamburskii (Hamburg Muscat), 5–8% CO₂ + 3–5% O₂ for Italia and 8% CO₂ + 5–8% O₂ for Galan.

Controlled atmosphere storage has been shown to reduce disease development and may be able to be developed as an alternative to SO₂ fumigation. Pre-treatment of Italia grapes with 20% CO₂ for 48 h before storage reduced decay during subsequent storage at 0 °C and 90–95% r.h. for 30 days in both conventionally and organically grown grapes. It had a marked effect during the first 10 days of cold storage on organic grapes (Massignan *et al.* 1999). CO₂ levels of 10–15% could control grey mould in grapes for limited periods, but prolonged exposure to these levels can damage the fruit, but up to 2 weeks' exposure did not have a detrimental effect (Kader 1989). Subsequently Kader (1997) indicated that levels of 15–20% could retard decay incidence of grapes. Kader (1989, 1992) recommended 0–5 °C in 1–3% CO₂ + 2–5% O₂ but reported that controlled atmosphere storage was incompatible with sulphur dioxide fumigation. However, Berry and Aked (1997) working on Thompson Seedless stored at 0–1 °C for up to 12 weeks showed that atmospheres containing 15–25% CO₂ inhibited infection with *Botrytis cinerea* by between

95 and 100% without detrimentally affecting their flavour.

Hypobaric storage

Burg (1975) found that hypobaric storage extended the postharvest life of grapes from 14 days in cold storage to as much as 60–90 days. Burg (2004) reported that Red Emperor could be stored for 90 days in reduced pressures of 30, 65, 80 or 160 mm Hg at 1.7–4.4 °C compared to 21–56 days at –0.5 to 0 °C at atmospheric pressure. Hypochlorous acid vapour was included to control diseases during hypobaric storage. Exposure to an airflow which had been in contact with hypochlorous acid at between 0.25, 1.5 or 5.25% had no mould after 60 days at 1.7–4.4 °C. The effectiveness of short hypobaric exposure against postharvest rots had also been investigated by Romanazzi *et al.* (2001). They found that exposure of bunches of Italia grapes to 0.25 atm. for 24 h significantly reduced the incidence of grey mould.

Hyperbaric storage

Romanazzi *et al.* (2008) stored Italia grapes for 24 h in pressures of 1140 mm Hg (1.5 atm.) and compared them with fruit at 760 mm Hg. They were stored at 2 ± 1 °C for 3 days. Hyperbaric storage resulted in a significant reduction of lesion diameter and percentage of *Botrytis cinerea* infections. They concluded that induced resistance was likely to be responsible for the decay reductions.

Modified atmosphere packaging

Artés-Hernández *et al.* (2006) stored the cultivar Superior Seedless in modified atmosphere packaging and found no changes in the phenolic compounds during storage at 0 and 8 °C, but a slight decrease during shelf life of 2 days at 20 °C. The cultivars Kyoho and Campbell Early packed in 0.03 mm PE film bags were stored for 60 days at 0 °C and 90% r.h. by Yang *et al.* (2007). They found that packaging in PE film maintained fruit firmness, total soluble solids, TA and skin colour, reduced respiration rate, decay and weight loss compared with those stored non-wrapped. In contrast grapes in antifogging and perforated film had increased decay and abscission.

Yamashita *et al.* (2000) stored the cultivar Italia at 1 °C and 85–90% r.h. followed by 25 °C and 80–90% r.h. in three different film bags, all of which had high gas permeability. Fruit in all three films stored well but Cryovac PD-955 had the longest storage life of 63 days compared with 11–21 days for fruit stored without packaging. Artés-Hernández *et al.* (2003) found that an equilibrium atmosphere of about 15% O₂ + 10% CO₂ gave the best results and for the cultivar Autumn Seedless 35 µm thick microperforated PP film provided this atmosphere. Investigations were conducted to study the effect of the ethylene absorber Sorbilen on storage quality of grapes, which showed that the inclusion of Sorbilen decreased storage decay (Lavrik *et al.* 2000).

Several workers have studied using modified atmosphere packaging in combinations with other treatments as an alternative to SO₂ treatment to control *Botrytis cinerea* in grapes.

Overall, the use of ozone and calcium chloride is two promising examples of treatments that are beginning to be adopted in a commercial scale. The requirements from the optimal treatment of grapes against grey mould before harvest or during storage are summarized Romanazzi *et al.* (2012)

Artés-Hernández *et al.* (2007) used ozone at 0.1 µl L⁻¹ O₃ and found that the sensory quality of the fruit was preserved with MA packaging giving an atmosphere of 13–16% O₂ + 8–11% CO₂ and in controlled atmosphere storage in 5% O₂ + 15% CO₂. Although O₃ did not completely inhibit fungal development, its application increased antioxidant compounds. A prestorage dip of the cultivar superior in either 33 or 50% ethanol then storage in sealed Xtend or PE film bags maintained grape quality for up to 7 weeks with shelf life of 3 days at 20 °C. The treatment was similar to or better than storage with SO₂ releasing pads (Lichter *et al.* 2005). Artés-Hernández *et al.* (2003) stored the cultivar Napoleon for 41 days in MA packaging or air followed by 4 days in air all at 0 °C then 3 days at 15 °C. The best results were by placing a soaked filter paper with 15 or 10 µl hexenal combined with sealing in microperforated PP of 35 µm thickness. Modified atmosphere packaging improved the visual appearance and reduced weight loss to 0.6% compared to no packaging which had 3.7% weight loss. Hexenal-treated fruit had the highest score for flavour and the lowest level of fungal disease (6%). Valverde *et al.* (2005) showed that the

addition of 0.5 µl of eugenol, thymol or menthol inside MA packages containing the cultivar Crimson Seedless reduced weight loss and colour change, delayed rates of pedicel deterioration retarded °Brix: acid ratio development, maintained firmness and reduced decay. Also the total viable counts for mesophilic aerobics, yeasts and moulds were significantly reduced in the grapes packaged with eugenol, thymol or menthol. The authors concluded that the inclusion of one of these essential oils resulted in three additional weeks storage compared to modified atmosphere packaging only. The equilibrium atmosphere in PP bags in storage at 1 °C was reached in 21 days with 1.2–1.3% CO₂ and 13–14% O₂. The inclusion of a sachet impregnated with either 0.5 ml thymol or 0.5 ml menthol inside the bag reduced yeasts, moulds and total aerobic mesophylic colonies and also improved the visual aspect of the rachis. The authors postulated that these essential oils could be an alternative to the use of SO₂ in controlling disease in table grapes (Martinez-Romero *et al.* 2005). Del Nobile *et al.* (2009) found that minimally processed grapes of the cultivar Italia retained their quality during storage at 5 °C using high barrier films during the 35-day storage period. Of the films they tested a multilayer film obtained by laminating nylon and a polyolefin layer and biodegradable polyester-based films NVT-100 gave the best results.

Diseases

During cold storage, grapes are susceptible to infection by many fungi including *Alternaria* spp., *Aspergillus niger*, *Botrytis cinerea*, *Cladosporium herbarum*, *Colletotrichum* spp., *Penicillium expansum*, *Phomopsis* spp. and *Rhizopus* spp. *R. stolonifer*, *R. oryzae* and the bacterium *Pseudomonas* (Snowdon 1990, Karabulut *et al.* 2004, Franck *et al.* 2005, Guzev *et al.* 2008). The most common diseases are given in the following discussion.

Grey mould *Botrytis cinerea* Pers.:Fr. teleomorph: *Botryotinia fuckeliana* (de Bary) Whetzel. It can develop in the field and spread rapidly among berries after harvest, during distribution, storage and shelf life. It is the most destructive of the postharvest diseases of grapes, primarily because it develops at temperatures as low as –0.5 °C. Healthy berries touching infected berries can become infected. No wound is required for infection in wet conditions but

damage near harvest can also provide opportunities for infections. Infected berries first appear soft and watery they turn brown, then the skin becomes loose and easily detached and the symptom is sometimes called slip skin. Subsequently white mycelium erupts through the skin and finally masses of grey coloured spores develop. Infected berries of white cultivars become brown and shrivelled and purple cultivars develop a reddish colour. Rotted berries generally shrivel and drop to the ground as hard mummies. Infection can be reduced by removing desiccated, infected grapes of the previous season from vines, leaf-removal canopy management. During growth bunches are sprayed with fungicides at various time after flowering almost up to the time of harvest. Harvested bunches are usually fumigated with SO₂. However, the use of synthetic fungicides and SO₂ are not allowed on organic grapes (Romanazzi *et al.* 2012).

Black rot *Aspergillus niger* Tiegh. Witbooi *et al.* (2000) found that an increase in harvest maturity was associated with increased susceptibility to *A. niger* infection during storage. *A. niger* was commonly found infecting grapes on markets in India and Bangladesh (Rathod 2010, Bashir *et al.* 2012).

Blue mould *Penicillium* spp. and *Penicillium digitatum* Sacc. also called Blue rot. The berries grow slowly and white mycelium that turns bluish green as powdery spores are formed on the surface. The berries decay and the infected tissues become soft and watery and have a mouldy smell and flavour. Avoiding injuries to the berries helps to reduce soft rot and the SO₂ treatments used to control grey mould also controls blue mould. *Penicillium* also infects the growing vine and avoiding field infections with clean planting material, removal and immediate burning of infected wood and fungicide application are important in its control.

Rhizopus rot *Rhizopus arrhizus* A. Fischer *R. stolonifer* (Ehrenb.:Fr.) Vuill. *R. oryzae* Went & Prinsen Geerligs. Irregular, light brown and water-soaked lesion with coarse white strands of mould that produce white spore heads that later turn brown appear on fruits. Decaying fruits may have a mouldy fermented smell. Preharvest fungicide application, careful handling of the fruit to reduce damage and the SO₂ treatments used to control grey mould also controls Rhizopus rot. Witbooi *et al.* (2000) found that an increase in harvest maturity was associated with increased susceptibility to *R. stolonifer* infection

during storage but growth was inhibited at -0.5 and 3 °C.

Aspergillus rot, Stalk end rot *Aspergillus niger* Tiegh. Infected berries have circular to oval, water-soaked spots that become soft and emit a bad sour smell. Infection usually begins at the stalk end. Spore heads are usually black. Preharvest fungicide application and bunch thinning help control the disease. Witbooi *et al.* (2000) found that an increase in harvest maturity was associated with increased susceptibility to *A. niger* infection during storage but growth was inhibited at -0.5 and 3 °C. Storage below 5 °C prevents development and the SO₂ treatments used to control grey mould also controls Aspergillus rot.

Anthraco-nose, Bird eye spot *Elsinoe ampelina* Shear anamorph: *Sphaeloma ampelinum* de Bary, also *Glomerella cingulata* (Stoneman) Spauld. & H. Schrenk, anamorph: *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz. It is a significant disease in regions with rainy, humid and warm climates. It is not a native pathogen to the United States and was most likely introduced via plant material imported from Europe in the mid-19th century. On berries reddish circular spots about 6 mm in diameter initially develop. The centres of the spots turn whitish grey and are surrounded by narrow reddish-brown to black margins. Acervuli eventually develop in the lesions. A pinkish mass of conidia exudes from these structures during prolonged wet weather condition. Wetness for 24 h or more and the temperature is above 3 °C splashing rain are spread the disease. Berry lesions can extend to the pulp, causing cracking and opening the berry to secondary infections. Lesions on the rachis and pedicels are similar to those of the shoots. Infection can occur on all parts of the plant and diseased leaves and twigs should be pruned and burnt. Infection of the fruit can occur at all stages of development from flowering onwards so regular fungicidal sprays are necessary. Resistant cultivars include Bangalore Blue, Beauty Seedless, Bharat Early, Concord, Delaware, Golden Queen, Large White, Moore's Early and Niagara. A few susceptible cultivars to avoid with heavy, poorly drained soil are Thompson Seedless, Cardinal and Queen of the Vineyards.

Rathod (2010) in a survey of postharvest fungal diseases of grapes from the Marathwada region of India identified: Anthracnose *Colletotrichum*

gloeosporioides and rots attributed to *A. niger*, *Penicillium* sp., *Botryodiplodia theobromae*, *Rhizopus stolonifer*, *R. nigricans* and *Phomopsis* sp. In Bangladesh five fungal species were isolated from the samples of rotten grapes on the markets of Dhaka. These were with their frequency of association: *Alternaria alternata* 13.3%, *Aspergillus flavus* 11.3%, *A. niger* 10.7%, *Syncephalastrum* sp. 12.7 and *Rhizopus nigricans* 19.3% (Bashar *et al.* 2012).

Disease control

Sulphur dioxide fumigation

SO₂ is the most common method used for controlling postharvest diseases of grapes (Pentzer and Asbury 1934, Couey and Uota 1961, Ryall and Harvey 1959) and is primarily used for controlling grey mould. Cooling must start as soon as possible and SO₂ applied within 12 h of harvest. It is important to apply SO₂ as soon as possible after harvest since it has limited effect on field infections with *Botrytis cinerea* and *Cladosporium herbarum*. In California SO₂ was first applied to fumigate grapes in precooling chambers from compressed gas cylinders with doses repeated at weekly intervals in storage rooms and occasionally within truck trailers and van containers during transport (Luvisi *et al.* 1992). One method was placing the boxes of fruit in a gas-tight room and introducing the gas from a cylinder to the appropriate concentration. A fumigation treatment that results in a residue of 5–18 µl L⁻¹ SO₂ in the fruit was found to be sufficient to control decay (Pentzer and Asbury 1934). Recommended application levels and exposure times may vary but generally 1% for 20 min directly after harvest and before precooling, then every 7–10 days with 0.25% for 20–30 min during storage. Treatment with 1% SO₂ for 20 min was found to be effective (Ryall and Harvey 1959). SO₂ toxicity to *B. cinerea* spores was found to be proportional to temperature over the range 0–30 °C where the toxicity increased about 1 1/2 times for every 10 °C rise in temperature (Couey and Uota 1961). American species are very sensitive to SO₂ and treatment is not recommended because they may suffer damage (Lutz and Hardenburg 1968, Anonymous 1968).

Sulphur dioxide pads

Special sodium metabisulphite-impregnated pads are available which can be packed into individual boxes

of fruit that give slow release of SO₂. The UVASYS SO₂ is a brand name for a patented laminated generating sheet that produces a predictable and consistent emission of SO₂ over a long period. This has the benefit of maximum fungal decay control combined with minimum SO₂ damage. These major advantages are in part owing to its unique plastic and wax/sodium metabisulphite matrix laminating process and in part owing to the precise and stringent quality control procedures in conjunction with manufacturing processes within the narrowest parameters of accuracy. Older technology sheets such as the plastic/paper granular sodium metabisulphate combination SO₂ generating sheets lack the precise nature of the UVASYS laminated sheet's technology (UVASYS 2012). Zutahy *et al.* (2008) described a dual-release SO₂ pad containing a quick-release plus a slow-release phase. They reported that the SO₂ level had reduced to below 1 µl L⁻¹ after 60–80 days at 0 °C. In order to extend the life of the pads they enclosed them in plastic laminate with macro-perforation and found that the optimum laminate had 32 perforations of 6 mm diameter. This pad was tested in storage at 0 °C for up to 116 days. Decay caused by *B. cinerea* and SO₂ damage was greater in the grapes with dual-release pads than the same pads in macro-perforated laminate. SO₂ pads have also been approved for the control of Phylloxera (*Daktulosphaira vitifoliae*). The Australian Government approved UVASYS sulphur dioxide generators, NUFARM FRESCA sulphur grape protection pads, plus other registered products containing 970 g kg⁻¹ INFRUTA sulphur dioxide pads, OSKU-VID grape guards plus other registered products containing: 980 g kg⁻¹ with sodium metabisulphite as their only active constituent at the rate of one standard pad/sheet per 10 kg carton/box of table grapes (Permit Number PER11748).

Restriction in the use of sulphur dioxide

Some people are intolerant of sulphur residues and concerns about sulphite residues in grapes led to it being reclassified as a pesticide with a residue tolerance of 10 mg kg⁻¹ for table grapes by the US Environmental Protection Agency (Anonymous 1989). Organic growers are prohibited from using SO₂ and organic grapes are particularly vulnerable to postharvest decay and have a short marketable life (USDA 2001). SO₂ can be corrosive, especially to metals, because it combines with atmospheric

moisture to form sulphurous acid. If applied in too high a concentration it can remove the colour from black or red grapes. As well as bleaching, injuries to the rachis and berries, excessive sulphite residues that can accumulate in grapes. Because of these challenges in the use of SO_2 a number of alternative means of disease control have been studied and these are described in the following sections.

Controlled atmosphere storage

Deng *et al.* (2005) reported that high O_2 storage conditions significantly reduced fruit decay, berry drop and softening, rachis browning and weight loss, delayed the decrease of soluble solids, TA and ascorbic acid, compared to storage in air. Pretel *et al.* (2006) reported that an atmosphere slightly enriched with CO_2 together with SO_2 generators slowed the rates of weight loss, softening and colour change and delayed fungal attack and rachis browning. Balic *et al.* (2012) also reported that after 90 days at 0°C those in CA storage had a lower percentage of rachis browning than those stored in air but after 2 days subsequent shelf life at 20°C the level was the same. Storage in atmospheres containing CO_2 levels of 10–15% can control *B. cinerea* for limited periods. However, prolonged exposure to these levels can damage the fruit, but up to 2 weeks exposure did not have a detrimental effect (Kader 1989).

Modified atmosphere packaging

Preventing *B. cinerea* growth also occurred with modified atmosphere packaging using chlorine gas generators (Zoffoli *et al.* 1999). Artés-Hernández *et al.* (2004) found that grapes in modified atmosphere packaging in a 35- μ thick microperforated PP film developed an atmosphere of about 15% O_2 + 10% CO_2 . This provided the best results in controlling postharvest diseases in grapes and also had a lower cost than SO_2 treatment. Chen *et al.* (2011) stored *V. vinifera* L. $\times$ *V. labrusca* L. cultivar Kyoho in MA packaging for short periods to investigate its residual effects on subsequent storage. They found that fruit stored in high barrier film bags giving a low O_2 and high CO_2 atmosphere for ≤ 2 weeks had potential for improving appearance of bunches and maintaining the quality of berries during subsequent storage at 0°C for 90 days in perforated bags. The fruits had significantly reduced quality deterioration, the stems were greener and berry drop and decay incidence were effectively controlled.

Ozone

It was reported that ozone had been successfully tested on grapes among other crops (Bordanaro 2009). Overall, the use of ozone and calcium chloride was two promising examples of treatments that are beginning to be adopted on a commercial scale (Romanazzi *et al.* 2012). Continued and intermittent (12 h per day) treatments with 2 ppm ozone were assessed during the storage of the cultivars Superior Seedless, Cardinal CL80 and Regina Victoria at 5°C for 72 days. Both ozone treatments considerably reduced decay compared to those stored in air, but ozone-treated grapes had lower scores in the sensory evaluation tests and also showed significantly higher weight losses than the fruits kept in air (Cayuela *et al.* 2009). Grey mould incidence was reduced among inoculated Autumn Seedless grapes from 91.7–19.3% by 1 h fumigation with $5000 \mu\text{L L}^{-1}$ ozone and this was reduced further to 10.0% when ozone fumigation and *Muscodor albus* biofumigation were combined. However, SO_2 pads reduced the incidence to 1.1%. The natural incidence of grey mould among organically grown Thompson Seedless grapes after 1 month of storage at 0.5°C was 31.0%. Fruit that had been fumigation with ozone had 9.7% and those with *Muscodor albus* biofumigation had 4.4%, while the combined treatment reduced grey mould incidence to 3.4% (Gabler *et al.* 2010). Ozkan *et al.* (2012) exposed inoculated grapes to $800 \mu\text{L L}^{-1}$ 1 h or more and found a reduction in the incidence of infected berries by 85% on Autumn Seedless and 45% on Scarlet Royal. They also showed that *P. digitatum* and *P. italicum* were more resistant to ozone than *B. cinerea*. Karaca *et al.* (2012) investigated the effects of ozone on postharvest treatment of fruit with several fungicides. They found that during storage at 2°C and 95% r.h. for 36 days there was an accelerated decline of fenhexamid, cyprodinil and pyrimethanil in the ozone atmosphere compared with air, but iprodione and boscalid were not affected. They concluded that ozone applied postharvest to control fungi may have a secondary benefit of reducing fungicide residues.

Ethanol

Chervin *et al.* (2003) reported preliminary results on the optimum ethanol dose for effective disease control. Stem browning was higher at $5 \text{ ml ethanol kg}^{-1}$ of fruit compared to SO_2 treatments and at a dose rate of 2 ml kg^{-1} , ethanol vapour was as effective

as SO₂ pads in disease control. Consumer panels detected no significant difference in sensory perception between controls and treated grapes. Pinto *et al.* (2006) reported that dipping the berries in ethanol could kill *Escherichia coli*, which might be important especially in minimally processed grapes. Lichter *et al.* (2003) dipped grapes in water at 50 °C for 15 min and found that infections with *B. cinerea* were retarded and the combination with ethanol enhanced the effect. Gabler *et al.* (2005) also found that dipping bunches in ethanol at 50 °C gave significant control of *B. cinerea* probably due to better ethanol penetration into the berries. Karabulut *et al.* (2004) also demonstrated that the addition of ethanol significantly improved the efficacy of a hot water treatment applied to grapes that had been inoculated with *B. cinerea*.

Acetaldehyde

Acetaldehyde fumigation of Sultanina grapes at 5000 µl L⁻¹ for 24 h was shown to reduce subsequent decay by 92% compared to untreated fruit and left no residues or off flavours in fruit (Avisar *et al.* 1989).

Essential oils

Essential oils have been studied for their use to control postharvest diseases but care must be taken to ensure safety because of potential toxicity in their use (Woolf 1999). *Thymus kotschyanus* and *Carum copticum* essential oils were studied on the mycelial growth of *B. cinerea* and *Penicillium digitatum* under *in vitro* condition. The results showed that *T. kotschyanus* and *C. copticum* essential oils in 300–500 µl L⁻¹ concentration completely inhibited the mycelial growth of *B. cinerea* and *P. digitatum* (Marandi *et al.* 2011). Major compounds found in essential oils from *T. kotschyanus* were carvacrol (28.54%) and in *C. copticum* were thymol (63.18%). They studied the effects on the cultivar Rish Baba *in vivo*. The application of essential oil did not affect the berry shrinkage and rachis browning but treatment showed high preservative effect on appearance, flavour, berry browning, TSS, titrable acidity and TSS:TA of treated fruits. Jobling (2000) reported work that showed that essential oils from red thyme (*Thymus zygis*), clove buds (*Eugenia caryophyllata*), cinnamon leaf (*Cinnamomum zeylanicum*) *Monarda citrodora* and *Melaleuca alternifolia* prevented the growth of *B.*

cinerea. She showed that tea tree oil prevented the growth of *B. cinerea in vitro* at concentrations of 100 ppm that gave 80% control and 500 ppm that gave 100% control. Camele *et al.* (2012) found that Citral and carvacrol at 250 ppm, and thymol at 150 and 250 ppm stopped the growth of *B. cinerea in vitro*.

Plant extracts

In trials on wounded fruit with extracts obtained from wild edible herbaceous species, *Orobancha crenata* extract strongly reduced grey mould on grapes (Gatto *et al.* 2012). Castillo *et al.* (2010) found that *Aloe vera* gel inhibited mycelium growth of *Penicillium digitatum* and *Botrytis cinerea in vitro*. *A. vera* gel at 250 ml L⁻¹ was applied to table grapes 1 and 7 days before harvesting. Fruit were harvested and stored for 35 days in a cold store and the respiration rate and weight loss were significantly reduced in treated fruits and colour change and softening were significantly delayed and the percentage of rotted berries was significantly lower in treated fruit compared to those that had not been treated with *A. vera*.

Biological control

Yeasts are members of the epiphytic microbial community on surfaces of fruits and vegetables and because some yeasts inhibit fungi they can be used as biocontrol agents. Yeasts were isolated from must and grape berries that exhibited *in vitro* inhibition of *B. cinerea* at 25 °C. These were tested *in vivo* and only one isolate, *Saccharomyces cerevisiae* BSc68, inhibited mycelial growth of *B. cinerea* on grape berries in storage at both 2 and 25 °C (Nally *et al.* 2012). Control of *B. cinerea* has also been achieved with high concentrations of the yeast *Aureobasidium pullulans* (Ippolito *et al.* 1998, Schena *et al.* 1999). Droby *et al.* (1998) also reported successful results by the application of yeasts and yeast-like fungi to restrict postharvest infections by *Botrytis*, *Rhizopus* and *Aspergillus* species. Another biological agent, *Cryptococcus laurentii*, was also reported as a promising organism to inhibit growth of many fungal species including *Botrytis cinerea*, *Penicillium expansum* and *Alternaria alternata*. A comprehensive review of postharvest biological control of fruits was given by Droby *et al.* (2011). The antifungal activity of different concentrations of *Thymus kotschyanus* and *Carum copticum*

essential oils at 300–500 μL^{-1} concentration were investigated *in vitro* and found to completely inhibit the mycelial growth of *B. cinerea* and *P. digitatum*. In laboratory experiments Romanazzi *et al.* (2012) reported that the biocontrol agents, *Muscador albus* and *Hanseniaspora uvarum*, have shown equal or better effectiveness than conventional methods to control *B. cinerea* of grapes *in vitro*. The commercial use of biocontrol agents is hampered by the registration process.

Chitosan

Chitosan is a natural biopolymer that must be dissolved in an acid solution to activate its antimicrobial and eliciting properties. Chitosan-based commercial products are available commercially and they have shown the same effectiveness as the biopolymer dissolved in an acid solution. Chitosan has been shown to reduce the growth of decay causing fungi and induce resistance responses in host tissues Romanazzi *et al.* (2006). Berries were inoculated with 1×10^5 *B. cinerea* conidia mL^{-1} before or after immersion of the fruit for 10 s in chitosan dissolved in 1% solution of acetic acid before storage. This treatment reduced grey mould during storage for 60 days both at 0.5 °C and ambient temperatures and did not injure the grapes (Romanazzi *et al.* 2009). They also showed that postharvest treatment in chitosan solutions and inoculated with the pathogen showed a reduction of incidence, severity and nesting of grey mould, in comparison with those not treated. Single berries artificially wounded, treated with chitosan and inoculated with *B. cinerea* showed a reduced percentage of infected berries and lesion diameter. The higher the chitosan concentration, over the range of 0.1, 0.5 and 1%, resulted in the greater decay reduction. All preharvest treatments significantly reduced the incidence of Grey mould, as compared to the control. Grapes treated with 1% chitosan showed a significant increase of phenylalanine ammonia-lyase activity. Consequently, besides a direct activity against *B. cinerea*, chitosan produced other effects contributing to reduce decay Romanazzi *et al.* (2002, 2012).

Romanazzi *et al.* (2006) tested that the effectiveness of chitosan treatment of table grapes, alone or in combination with UV-C, to control postharvest Grey mould was determined in California, USA. Clusters

of cultivars Thompson Seedless, Autumn Black and Emperor were sprayed in the vineyard with 1% chitosan and then harvested daily for 5 days. Promptly after harvest, they were inoculated with *B. cinerea*. Decay incidence and disease severity were significantly reduced by chitosan, which was most effective on berries harvested 1 or 2 days after treatment. In another experiment, grapes were sprayed in the vineyard with chitosan, harvested 2 days later, irradiated for 5 min with UV-C (0.36 J cm^{-2}) and inoculated with *B. cinerea* 2 days later. Combined chitosan and UV-C treatments applied to the cultivar Autumn Black or B36-55 were synergistic in the reduction of grey mould incidence and severity compared to either treatment alone. Sánchez-González *et al.* (2012) recommended coating for Muscatel grapes with chitosan-containing bergamot oil, which showed antimicrobial activity and reduction in their respiration rate and water loss during storage.

American species are susceptible to *Botrytis cinerea*, *Colletotrichum gloeosporioides*, *Botryosphaeria dothidea*, *Uncinula necator*, *Penicillium*, *Alternaria alternata* and *Cladosporium herbarum*. Undeveloped berries can show infection by black rot caused by *Guignardia bidwelli* (Perkins-Veazie 2002b). American species are very sensitive to sulphur dioxide, a treatment commonly used on *V. vinifera* to control mould, and it is not recommended for American species because they will suffer damage (Lutz and Hardenburg 1968, Anonymous 1968).

Postharvest disorders

Shattering

Shattering is where the individual berries become dislodged from the bunch. Shattering can occur during production, at harvest and during storage. There are two types of shattering. Physiological shattering, which was due to the formation of an abscission layer at the base of the pedicel where it is attached to the berry and decay shattering was where a remnant of the pericarp was attached at the pedicel. In general, shatter increases in severity with increasing maturity. Berries of seedless cultivars are usually less well attached to the cap stem than seeded cultivars. Shatter varies considerably from season to season, and there is a large difference among cultivars. Shatter occurs mainly due to rough handling during field packing

with additional shatter occurring all the way to the final retail sale.

Inoculation experiments indicated that *Botrytis cinerea*, *Alternaria* sp. and *Rhizopus stolonifer* contributed both to decay and physiological shattering. Sprays of iprodione 65 and 9 days before harvest or wrapping in SO₂ generating paper sheets markedly decreased berry shattering during storage at 5 °C for 2 months (Xu *et al.* 1999). Shatter incidence can be reduced by controlling pack depth and fruit packing density, using cluster bagging, gentle handling and maintaining recommended temperature and relative humidity (UC Davis n.d.).

Dehydration

Fruits lose water through the skin that is thin in grapes that may result in high water loss. Excessive water loss during storage can cause browning of the fruit stalk and loss of their bright turgid appearance in grapes (Lutz and Hardenburg 1968). The use of cluster bags and foam boxes reduced grape cluster water loss during harvest operations (Crisosto and Dokoozlian 2001). Rachis (the axis bearing berries) browning, which occurs as a consequence of water loss, reduces table grape marketable quality (Capellini *et al.* 1986).

Waterberry

Waterberry is associated with fruit ripening and most often begins to develop shortly after véraison. The earliest symptom is the development of dark spots 1–2 mm in diameter on the pedicles. These spots become necrotic, slightly sunken and expand to affect more areas. The affected berries become watery, soft and flabby when ripe. In California, this disorder has been associated with a high nitrogen status vine, canopy shading or cool weather during véraison and fruit ripening. Foliar nutrient sprays of nitrogen should be avoided where waterberry occurs (UC Davis n.d.).

Pests

Mitcham *et al.* (1997) showed that high CO₂ levels in the storage atmosphere could be used for controlling insect pests of grapes. In trials where four cultivars were exposed to 0 °C in 45% CO₂ + 11.5% O₂ complete control of *Platynota stultana*, *Tetranychus pacificus* and *Frankliniella occidentalis* was achieved without injury to the grapes.

Postharvest losses

Masarirambi *et al.* (2010) reported that from developing countries like Swaziland the magnitude of postharvest losses of fruits and vegetables can reach up to 50%. Sharma *et al.* (2011) reported that postharvest infrastructure in India is inadequate and losses of fruit are high. In a review of postharvest losses Thompson (1996, quoted Harvey 1978) as 4.2% due to mechanical damage, 0.4% to diseases and 0.9% to disorders on the New York retail market and 27% overall in developing countries in a review by Anonymous (1978). In Pakistan the aggregate postharvest losses in grapes were reported to range from 16% to 23%, depending on methods of marketing. Losses were mainly due to improper packing and transportation a poor marketing infrastructure (Aujla *et al.* 2011).

Transport

To reduce vibration injury specially sprung lorries or bubble polyethylene film liners at the bottom of crates can be used for transport of grapes (John Love, personal communication, quoted by Thompson 1996). The Agricultural Produce Export Development Authority in India started to export grapes, to the United Kingdom, around 1990–1991. The sea voyage to England in reefer containers took about 3 weeks and allowing for transport to the retail stores and some storage time in distribution, the grapes had to appear fresh and attractive for 6 weeks at least after harvest (Aswaney 2007).

Quarantine

Several countries have regulations to control pests and diseases being imported. One insect that can affect shipments of grapes is the vine moth *Lobesia boltrana* which has been reported in Africa, Europe and Japan (Burg 2004). Chile had a special entry permit issued for export to Japan with the proviso that Mediterranean fruit fly is controlled by cold treatment of 0 °C for 12 days (Kitagawa 1993). False codling moth (*Thaumatotibia leucotreta*) is major pest of South Africa's Western Cape fruit which was controlled by 17 days exposure to −0.6 °C. This is a shorter time than apples, pears and grapes were exposed to −0.5 °C. This exposure was already used for a disinfestation treatment against Tephritidae in the Western Cape for both grapes and apples. Vapour

heat treatment was unsuccessful against Tephritidae in grapes. However, vapour heat applied at 44 or 46 °C for 3.5 h (Pryke and Pringle 2008). A widely used agent in disinfestation procedures, methyl bromide, was scheduled to be withdrawn in many countries in 2005 because of its ozone-depleting properties. The main alternatives are irradiation, extreme temperatures, forced air, vapour heat methods and the use of controlled atmospheres. Heather and Hallman (2008) reported that irradiation has the potential to solve many phytosanitary problems and is generally the most tolerated treatment for fresh commodities. Kang *et al.* (2012) discussed X-ray irradiation as a quarantine treatment for exports of grapes. They found that 0.2 and 0.4 kGy X-ray irradiation reduced the respiration rate of grapes and extended their shelf life. There was no significant effect of irradiation on other physical and chemical properties and those that were irradiated had a better appearance than the control grapes after 14 days. Al-Bachir (1999) had previously evaluated the effect of γ -irradiation on the cultivars Baladi and Helwani in Syria. They also found that the storage period was extended by 50% after treatment with 0.5–1.0 kGy for Helwani and 1.5–2.0 kGy for Baladi.

Grapefruit

Rutaceae

Citrus pardisi Macf. The grapefruit is thought to have originated as a mutation of the pomelo (*C. grandis*) in the West Indies. The grapefruit was first described in 1750 by Griffith Hughes who called it the forbidden fruit of Barbados. In 1789, Patrick Browne reported it as growing in most parts of Jamaica. In 1814, John Lunan, in *Hortus Jamaicensis*, mentions the grapefruit as 'a variety of the shaddock, but not as large; having a thin, tough, smooth, pale yellow rind.' In 1824, DeTussac mentions the forbidden fruit or smaller shaddock of Jamaica as a variety of shaddock the size of an orange and borne in bunches (Morton 1987).

The evergreen tree generally grows up to 6 m tall. The white flowers are borne singly or in clusters in the leaf axils. The fruit is a berry or hesperidium and is almost round or oblate to slightly pear-shaped up to 15 cm wide. It has smooth peel finely dotted, up to 1 cm thick, yellow, sometimes blushed with pink.

The pulp is whitish, pink or red in 11–14 segments, acid to sweet-acid in flavour when fully ripe. They may be seedy or seedless, and unlike pummelo, grapefruit seeds are usually polyembryonic. On the tree the number of fruits in a cluster varies up to as many as 20. The climate in which they are grown can affect their composition. For example fruit had lower acidity in the Indian River region and areas of southern Florida, the lower Rio Grande Valley of Texas and in the tropics than those grown in cooler climates (Morton 1987). The fruit will freeze at about –2.2 to –1.7 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 106. Total world production of grapefruit including pomeles in 2010 was estimated by FAO (2013) as 7,109,485 tonnes.

Gallagher (2012) reported that furanocoumarins in grapefruit destroy an enzyme that breaks down

Table 106 The composition of grapefruit fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	Pink, red and white	White
Water (g)	90.89	90.48
Energy (kcal)	32	33
Protein (g)	0.63	0.69
Total lipid (fat) (g)	0.10	0.10
Carbohydrate, by difference (g)	8.08	8.41
Total dietary fibre (g)	1.1	1.1
Total sugars (g)	6.98	7.31
Calcium (mg)	12	12
Iron (mg)	0.09	0.06
Magnesium (mg)	8	9
Phosphorus (mg)	8	8
Potassium (mg)	139	148
Sodium (mg)	0	0
Zinc (mg)	0.07	0.07
Total ascorbic acid (mg)	34.4	33.3
Thiamine (mg)	0.036	0.037
Riboflavin (mg)	0.020	0.020
Niacin (mg)	0.250	0.269
Vitamin B-6 (mg)	0.042	0.043
Folate (µg DFE)	10	10
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg RAE)	46	2
Vitamin A (IU)	927	33
Vitamin E (α-tocopherol) (mg)	0.13	0.13
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phyloquinone) (µg)	0.0	0.0
Fatty acids, total saturated (g)	0.014	0.014
Fatty acids, total monounsaturated (g)	0.013	0.013
Fatty acids, total polyunsaturated (g)	0.024	0.024

some commonly taken drugs, including statins, with the result that much more of the drug escapes the digestive system than the body can handle. Other citrus fruits such as Seville oranges (*C. aurantium*) and limes (*C. aurantifolia*) were reported to have the same effect. Another report indicated a link between grapefruit consumption and breast cancer in post-menopausal women. It was thought to be related to increased levels of oestrogen, which is the hormone associated with a higher risk of the disease. Dr Joanne Lunn was quoted in reference to this report, 'This is an interesting study of a large group of post-menopausal women whose diet and health have been followed for many years. However, this study is simply a piece of the jigsaw that will eventually help us to understand how our diets affect our health. Although we are beginning to get a better awareness of how our diets can modify the risk of diseases such as cancer, we are still a long way from identifying particular foods that might specifically increase or decrease risk.' (16 July 2007, <http://news.bbc.co.uk/1/hi/health/6900482.stm>).

Harvesting

It is important, like other citrus fruits, to harvest them at peak maturity since they do not ripen after harvest, only deteriorate (Anonymous 1968). The juice content increases as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit it is possible to specify its maturity. In the United States the minimum value is 35%. The ratio between TSS and TA can also be used with ranges of 5:1–7:1. Jordan *et al.* (2001) recognizing that sugar and acid have the opposite effect on flavour, and that the human taste buds are more sensitive to acidity. Therefore they proposed subtracting TA from TSS after multiplying TA by a constant that differs by fruit type. This measurement index, given the name of BrimA, was found by the authors to be more closely related to flavour than TSS:TA. Other methods of assessing harvest maturity include peel colour, aroma and time after flowering. Grapefruit change from green to yellow as they mature and aromatic compounds increase. Both of these should be taken into account when harvesting. The temperature during growth can affect the length of time from flowering to fruit maturity.

For example at Riverside in California it was said to take 13 months from flowering to fruit maturity, while at the warmer Brawley in the Imperial Valley of southern California it took only 7–8 months (Morton 1987).

They should be clipped from the tree, not pulled and not harvested when wet. Quailing for a short time before transport from the field has been recommended to reduce oleocellosis, toughen the skins and make them less prone to injury and infection (Wardlaw 1937). However, it is rarely practised today. Anonymous (1972) reported the use of a shaker for harvesting grapefruit. The trees had to be pruned to remove deadwood and to give access to 3–5 main branches for shaking and the lower branches cut off to leave a clear 75 cm space for the catching frame. Mechanical harvesting caused some superficial injury, but presumably this was acceptable especially if the fruit was to be processed.

1-MCP

Treatment with 1-MCP at concentrations equal to or greater than 75 nl L⁻¹ inhibited ethylene-induced degreening but the effect was transient, and increasing 1-MCP concentrations to greater than 150 nl L⁻¹ did not cause additional inhibition of degreening. Exposure to 15 and 75 nl L⁻¹ 1-MCP resulted in a slight suppression of respiration rate, while 150 or 300 nl L⁻¹ 1-MCP resulted in higher respiration rates than non-exposed fruit. 1-MCP treatment also resulted in an increase in the rate of ethylene production that was dose and time dependent. The effects of 1-MCP on respiration rate and ethylene production were significantly reduced if fruit were subsequently exposed to ethylene. Rates of ethylene evolution were some 200 nl kg⁻¹ h⁻¹ from control and ethylene-treated fruit compared to about 10,000 nl kg⁻¹ h⁻¹ from 1-MCP-treated fruit. Fruit treated with ethylene following 1-MCP treatment had ethylene production rates of about 400 nl kg⁻¹ h⁻¹ (McCollum and Maul 2009).

Postharvest physiology

It is a non-climacteric fruit. Respiration rates were higher at higher temperature as would be expected (Table 107). Respiration rates at optimum storage temperature were given as less than 10 mg CO₂

Table 107 Effects of temperature on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{h}^{-1}$) of grapefruit grown in Florida (source: adapted from Haller *et al.* 1945)

Temperature ($^{\circ}\text{C}$)	0	4.4	10	15.5	21.1	26.6	32.2	37.7
Respiration rate	2.6	4.5	6.9	13.2	16.0	19.0	27.5	51.4

$\text{kg}^{-1} \text{h}^{-1}$ and the rate of ethylene production was typically less than $0.1 \mu\text{l kg}^{-1} \text{h}^{-1}$ at 20°C (Arpaia and Kader 2000).

Storage

Chilling injury can occur as skin pitting, which increases in size and eventually develops the fruit rots. Hatton and Cubbedge (1983) reported that it occurred during prolonged storage at 10°C and the degree of chilling injury was higher on the fruits on the outside of the tree than those that have been sheltered by foliage. They also found that preconditioning at 16°C for 7 days before storage at 1°C prevented chilling injury, and lowering the temperature gradually after preconditioning was also beneficial as did storage in 100% r.h. Waxing and storage in Pliofilm (rubber hydrochloride) (Grierson 1971) or PE shrink film (Hatton and Cubbedge 1983) reduced chilling injury. Marsh Seedless fruits that had been dipped in methyl jasmonate at $10 \mu\text{M}$ for 30 s and then stored at 2°C for 4–10 weeks had reduced severity of chilling injury symptoms and the percentage of fruits showing chilling injury compared to fruit that had not been treated (Meir *et al.* 1996). General refrigerated storage recommendations were 7°C and 85–90% r.h. for 10 weeks (Anonymous 1967) and 5.6 – 7.2°C and 85–90% r.h. for 8–12 weeks (Pantastico 1975). Recommendations for different areas of production include:

Australia

- 7.2 – 10°C (Wardlaw 1937).

Arizona

- 14.4 – 15.6°C and 85–90% r.h. (Lutz and Hardenburg 1968);
- 14 – 15°C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 13.3°C and 85–90% r.h. for 28–42 days (SeaLand 1991).

California

- 14.4 – 15.6°C and 85–90% r.h. for 4–6 weeks (Lutz and Hardenburg 1968);
- 14 – 16°C and 85–90% r.h. for 4–8 weeks (Mercantilia 1989);
- 14 – 15°C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 13.3°C and 85–90% r.h. for 28–42 days (SeaLand 1991).

Florida

- 10°C and 85–90% r.h. for 4–6 weeks (Mercantilia 1989, Hardenburg *et al.* 1990);
- 0°C for 3–4 weeks but must be marketed within 3–4 days (Hardenburg *et al.* 1990);
- 10°C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 13.3°C and 85–90% r.h. for 28–42 days (SeaLand 1991);
- 10°C for fruit harvested after January in Florida (Davies and Albrigo 1994);
- 15°C for fruit harvested before January in Florida (Davies and Albrigo 1994).

Israel

- 6 – 9°C and 85–90% r.h. for 3–4 months (Mercantilia 1989);
- 10 – 12°C and 90% r.h. for 10–16 weeks (Snowdon 1990).

Mexico

- 13.3°C and 85–90% r.h. for 4–6 weeks (SeaLand 1991).

South Africa

- 11°C and 90% r.h. for 12–14 weeks (Snowdon 1990).

Texas

- 10°C and 85–90% r.h. for 4–6 weeks (Hardenburg *et al.* 1990);
- 10°C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 13.3°C and 85–90% r.h. for 4–6 weeks (SeaLand 1991).

Trinidad

- 7.2°C for 50–60 days (Wardlaw 1937).

The United States

- 10 – 12.8°C and 88–92% r.h. for 60–90 days (Wardlaw 1937).

Controlled atmosphere storage

Controlled atmosphere storage experiments have given inconclusive results with some indication that fruit stored in 10% CO₂ at 4.5 °C for 3 weeks had less pitting than those stored in air. Pretreatment with 20–40% CO₂ for 3 or 7 days at 21 °C reduced physiological disorders on fruit stored at 4.5 °C for up to 12 weeks (Hardenburg *et al.* 1990). Other recommendations include:

- 5–10% CO₂ with 3–10% O₂ for grapefruit from California, Arizona, Florida, Texas and Mexico (SeaLand 1991);
- 10–15 °C with 5–10% CO₂ and 3–10% O₂ had a fair effect on storage, but controlled atmosphere storage was not used commercially (Kader 1985, 1993);
- 10–15 °C and 85–90% r.h. with 6–8% O₂ and 3–10% CO₂ for 6–8 weeks (Burden 1997).

In experiments with Star Ruby grown in Turkey, which compared 1, 3 or 5% CO₂ and all at 3% O₂ and 10 °C, the best conditions were 1% CO₂ and 3% O₂ giving 125 days of storage with little loss of quality (Erkan and Pekmezci 2000).

Hypobaric storage

Haard and Salunkhe (1975) mentioned two reports which suggested that low pressure storage could extend the postharvest life compared to cold storage alone. In one report the increase was from 20 days at normal pressure to 3–4 months in hypobaric conditions, and in the other from 30–40 days at normal pressure to 90–120 days in hypobaric storage. Hypobaric storage at 380 mm (the lower limit of the experimental equipment) and 4.5 °C had no effect on the incidence of chilling injury (Grierson 1971).

Degreening

Optimum temperatures for degreening range between 25 and 29 °C and humidity as high as possible, generally between 90 and 95% r.h. with ethylene at between 1 and 10 µl L⁻¹ for 24–72 h. The actual choice of conditions will vary between different situations, the cultivar and the stage of maturity at harvest. Mayuoni *et al.* (2012) found that ethylene degreening had no effect on juice TSS and TA contents and had only minor effects on contents

and composition of juice aroma volatiles in the cultivar Star Ruby. Also sensory analysis tests showed that ethylene degreening did not affect their flavour.

Diseases

Green mould (*Penicillium digitatum*) and blue mould (*P. italicum*) are the major postharvest diseases. They invade fruit through wounds made during handling. Growth of *P. digitatum* is more favourable at temperatures above 10 °C, whereas growth of *P. italicum* occurs more readily at lower temperatures (Snowdon 1990). Curing has been shown to give good control. Sealing in plastic film bags and then exposing them to 34–36 °C for 3 days resulted in the inhibition of *P. digitatum* infection through lignification and an increase in antifungal chemicals in the peel of the fruit (Ben Yehoshua *et al.* 1989b). Sealing the fruit in plastic film before curing was said to be essential to reduce weight loss (Ben Yehoshua *et al.* 1989a). Hot water brushing has also been used to control postharvest diseases. Storage experiments using organically grown Star Ruby showed that hot water brushing at 56 °C for 20 s reduced decay development by 45–55% and did not cause surface damage. Also it did not influence fruit weight loss or internal quality parameters (Porat *et al.* 2000).

Stem-end rot (*Diplodia natalensis*) develops as latent infections on the calyx and can grow through the core after harvest. The decay develops unevenly at the stem and stylar ends resulting in wavy margins. Minimizing degreening time by delaying harvest will assist in controlling stem-end rot. Development of *Phomopsis citri* is favoured in the subtropics when temperatures are low and degreening is no longer necessary. *Alternaria citri* is a less aggressive fungus that can be problematic in over-mature grapefruit and those in extended storage. Often the symptoms of *Alternaria*, internal black discolouration generally towards the stem end, are not visible until the fruit are cut. Brown rot (*Phytophthora citrophthora*) appears more frequently in mature fruit and fruit stored for longer durations at low temperatures. Immature fruit are resistant to sour rot (*Geotrichum candidum*) infection, but as the fruit mature, the disease can become a problem. Drenching harvested grapefruit with thiabendazole before arrival at the packhouse is recommended for *Diplodia*, *Phomopsis*, *Glomerella* and *Penicillium* control. In addition, application

of aqueous imazalil or thiabendazole in the wax treatment aids in control (Eckert and Brown 1986, Snowden 1990).

Physiological disorders

High water loss from fruits can cause areas of the skin to become brown and necrotic. This often starts from the stem end.

Guava

Myrtaceae

Psidium guajava L. It is native to the American tropics and was reported to be common in many parts of the West Indies in 1526. It was taken by the Spaniards to the Philippines and the Portuguese to India (Purse-glove 1975). The tree is a tropical and subtropical evergreen usually quite small and rarely up to 8 m high. The fruit is a berry with a persistent calyx and is borne directly on the trunk or branches of the tree. They are usually pear shaped, but can be round and are up to 15 cm long (Figure 93). Charley (1969) gave the ascorbic acid content for common guava in mg 100 g⁻¹ as 23–486 in Florida, 96–306 for Hawai'i, 50–352 for California (outer flesh), 202–442 for Puerto Rica, 299 for India (country variety), 11–19 for India (hill variety) and 110 for long yellow in Australia. Levels of polyphenols, particularly the high molecular weight polyphenols, in guava were shown to decrease as the fruit matured with young fruit



Figure 93 Guavas grown in Thailand and packed ready for the market. There are some large cultivars in Thailand that are crisp and sweet when still unripe and can be eaten like desert apples. See colour plate section.

Table 108 The composition of guava fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	80.80 g	Thiamine	0.067 mg
Energy	68 kcal	Riboflavin	0.040 mg
Protein	2.55 g	Niacin	1.084 mg
Total lipid (fat)	0.95 g	Vitamin B-6	0.110 mg
Carbohydrate, by difference	14.32 g	Folate	49 µg DFE
Total dietary fibre	5.4 g	Vitamin B-12	0.00 µg
Total sugars	8.92 g	Vitamin A	31 µg RAE
Calcium	18 mg	Vitamin A	624 IU
Iron	0.26 mg	Vitamin E	0.73 mg
		(α-tocopherol)	
Magnesium	22 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	40 mg	Vitamin D	0 IU
Potassium	417 mg	Vitamin K	2.6 µg
		(phylloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.272 g
Zinc	0.23 mg	Fatty acids, total monounsaturated	0.087 g
Total ascorbic acid	228.3 mg	Fatty acids, total polyunsaturated	0.401 g

containing 620 mg 100 g⁻¹ fresh weight of polyphenols of which 65% were condensed tannins (Ito et al. 1987). Over 80 volatile aroma compounds have been identified in guava fruit. The production of volatile chemicals has been shown to change during maturation of guava. As the fruit matures the production of isobutanol, butanol and sesquiterpenes decreases and in mature and ripe fruit ethyl acetate, ethyl caproate, ethyl caprylate and *cis*-hexenyl acetate are high (Askar et al. 1986). β-Caryophyllene was identified as an important volatile associated with the aroma of guava (McLeod and de Troconis 1982). The chemical content was given by USDA (2012) in Table 108. Total world production of mangoes, mangosteens and guavas in 2010 was estimated by FAO (2013) as 37,124,742 tonnes.

Harvesting

In India the cultivar Sardar exhibited a sigmoid pattern of growth and took 126 days from fruit set to attain harvest maturity (Rao et al. 1995). A steady increase in TSS of the cultivar Allahabad Safeda occurred up to 120 days after fruit set, while total pectic substances increased for 90 days and then declined (Majumder and Mazumdar 1998). Generally harvest

maturity is judged by the skin becoming smoother, less green in colour and the development of their distinct odour. Guavas have a strong aroma, which develops during ripening. The aroma volatiles may be evident at an early stage of ripeness; it is thought that these may be involved in attracting fruit flies that often attack the fruit as they begin to ripen. One way to reduce fruit fly infestation is to harvest at an early stage of maturity before the aroma volatiles have been synthesized, but this would have a detrimental effect on their flavour.

The trees are usually small so harvesting is by hand where mature fruits are easily selected. The meadow orchard system of production can be used to facilitate mechanical harvesting. This is where the whole of the tree is harvested just above the ground each year or every other year. The fruit are then separated from the stems in machines in the packhouse (Mohammed *et al.* 1984). The tree regrows from the stump left in the ground and the cycle continues.

Calcium treatment

In India preharvest application of 1% calcium nitrate resulted in the lowest mean loss in weight (5.6%), lowest respiration rate ($64.9 \text{ mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$) and maintained the firmness of fruits during storage longer than the untreated fruit or those sprayed with other calcium nitrate concentrations. This treatment also resulted in the highest mean TSS and ascorbic acid contents, 13.8% and 272.7 mg per 100 g pulp, respectively, the lowest mean acidity value (0.64%) and lowest incidence of disease (caused by *Pestototia psidii*) after 9 days of storage (Singh and Singh 1999). The storage life at $28\text{--}30^\circ\text{C}$ was doubled to 12 days when fruits of the cultivar Baladi were dipped in a mixture of 2% calcium chloride and 2% corn flour (Amen 1987). Fruits immersed for 20 min in 0.5 or 1.0% calcium solution maintained marketable quality for up to 16 days at 10°C and 90% r.h. (Gonzaga Neto *et al.* 1999).

1-MCP

In the cultivar Allahabad Safeda 1-MCP treatment at $20 \pm 1^\circ\text{C}$ reduced ethylene production, respiration rate, softening, TSS and TA during storage at both 10°C and $25\text{--}29^\circ\text{C}$ depending on 1-MCP concentration and exposure duration. Vitamin C content

in 1-MCP-treated fruit was significantly higher, and there was a significant reduction in the decay compared to non-treated fruit. Also the development of chilling injury symptoms was ameliorated to a greater extent in 1-MCP-treated fruit. It was reported that 1-MCP at 600 nL L^{-1} for 12 h and storage at 10°C seemed a promising way to extend the storage life, while 1-MCP at 300 nL L^{-1} for 12 and 24 h or 600 nL L^{-1} for 6 h may be used to provide 4–5 days extended marketability of fruit under ambient conditions of $25\text{--}29^\circ\text{C}$ (Singh and Pal 2008a).

Postharvest physiology

It was classified as a non-climacteric fruit by Biale and Barcus (1970), but other workers including Paull and Chen (2002b) classified it as climacteric, and they gave ethylene production rates that varied between 1 and $20 \mu\text{L kg}^{-1} \text{ h}^{-1}$ at 20°C depending on cultivar and stage of ripeness. They also gave respiration rates as 8–60 at 10°C and $18\text{--}130 \text{ mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 20°C . Akamine and Goo (1979a) reported that the *P. guajava* cultivars Beaumont and Allahabad Safeda as well as *P. cattleianum* and *P. cattleianum* f. *lucidum* were climacteric and that the increase in ethylene production preceding the rise in respiration rate by 1 day. In more recent work Te-Chun Liu *et al.* (2012b) found that during storage at 20°C fruit of the cultivar Li-Tzy Bar harvested at the mature-green stage exhibited ripening behaviour typical for a climacteric fruit. This included increases in respiration rate to $3.75 \text{ mmol CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ and ethylene production to $1.37 \times 10^3 \text{ nmol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$ at peak levels. Li-Tzy Bar also changed colour from green to yellow, the flesh softened and aroma volatiles were produced. By contrast, the cultivar Jen-Ju Bar was considered a non-climacteric fruit because its respiration rate was stable at $0.61\text{--}0.73 \text{ mmol CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ and ethylene production was less than $4 \text{ nmol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$. It also retained its pale-green colour and firmness throughout a 20-day observation period. To confirm this by exposure to exogenous ethylene or propylene they found that the ripening characteristics of Jen-Ju Bar did not result from a defect in ethylene signalling, but instead resulted from a lack of autocatalytic ethylene synthesis. However, a cutting treatment of Jen-Ju Bar was able to induce stress-responsive ethylene production expected from system 1 ethylene biosynthesis. They suggested that insufficient

ACC synthesis (1-aminocyclopropane-1-carboxylic acid), the reaction catalysed by ACC synthase, prevented system 2 ethylene biosynthesis in Jen-Ju Bar fruit. Mercado-Silva *et al.* (1998) found that acidity decreased during development while ascorbic acid and TSS increased during the last stage of growth.

Storage

Storage at ambient temperatures is characterized by a relatively short shelf life because of the rapid development of fungal rots. Wills *et al.* (1983) quoted a life of about 1 week at 20 °C for the cultivars 1050 and GA 11–56. At 25–30 °C Singh and Mathur (1954) showed that Safeda had a shelf life of only 3 days. The cultivars Chittidar and Sardar had a storage life of 9 days, and Allahabad Safeda 6 days at 16–20 °C and 80–85% r.h. (Singh 1990). At 20 °C and 60% r.h. shelf life was reported to be 7–10 days (Mercantilia 1989). Chilling injury was reported to occur during storage at 0–2.2 °C (Lutz and Hardenburg 1968). Wills *et al.* (1983) also showed that fruit stored at 0 °C suffered from chilling injury, but had lower levels of rotting. Refrigerated storage recommendations include:

- 8–10 °C and 85–90% r.h. for 4 weeks for Safeda (Singh and Mathur 1954);
- 2–7 °C for a week for fully ripe fruit with only minimal loss of ascorbic acid (Boyle *et al.* 1957);
- 7–10 °C and 85–90% r.h. for about 3 weeks (Lutz and Hardenburg 1968);
- 8.3–10 °C and 85–90% r.h. for 2–5 weeks with 14% weight loss (Pantastico 1975);
- 5 °C (Wills *et al.* 1983);
- 10 °C and 90% r.h. for 3 weeks (Mercantilia 1989);
- 5–10 °C and 90% r.h. for 2–3 weeks (Hardenburg *et al.* 1990);
- 3.5–7 °C for several weeks (Vasquez Ochoa and Colinas Leon 1990);
- 5–10 °C and 90% r.h. for 2–3 weeks (Snowdon 1990);
- 10 °C and 85–90% r.h. for 14–21 days (SeaLand 1991).

Controlled atmosphere storage

Freshly harvested mature green fruits of the cultivar Lucknow-49 were stored at 8 °C with 85–90% r.h. in 5% O₂ + 2.5% CO₂ or 10% O₂ + 5% CO₂. CA stored fruit could be kept in an unripe condition

for 1 month, while those stored in air at the same temperature had severe chilling injury symptoms, high weight loss, softening and colour change (Pal *et al.* 2007). Subsequently Singh and Pal (2008a) investigated 2.5, 5, 8 and 10% O₂ factorially combined with 2.5, 5 and 10% CO₂ (balance N₂) at 8 °C and 85–90% r.h. They successfully stored the cultivars Lucknow-49, Allahabad Safeda and Apple Colour for 30 days in 5% O₂ + 2.5% CO₂, 5% O₂ + 5% CO₂ or 8% O₂ + 5% CO₂. The fruit were then transferred to ambient conditions of 25–28 °C and 60–70% r.h. and they all ripened successfully. Chilling injury and decay incidence were reduced during ripening of fruit that had been stored in CA compared to those that had been stored in air. However, larger amounts of ethanol and acetaldehyde accumulated in fruit held in atmospheres containing 2.5% O₂. Bautista and Silva (1997) exposed fruit to 10% O₂ + 5% CO₂ for 24 h before storage in air at 4 °C for 2 weeks and found that there was delayed colour development and reduced chilling injury compared to those stored in air at the same temperature.

Modified atmosphere packaging

All fruits of the cultivar Kumagai stored well at 7 °C and 80–90% r.h. for up to 37 days when sealed in LDPE, PP or heat shrinkable copolymer films. They were of good flavour and acceptable appearance compared with those stored non-packed. However, Yamashita and Benassi (1998) found that fruits sealed in polyester film developed off-flavour after 17 days. It was found that when fruits of the cultivar Paluma were harvested just before ripening (fruits reaching complete growth but still with green peel) they maintained marketable quality for up to 16 days when stored in PE bags and stored at 10 °C and 90% r.h. (Gonzaga Neto *et al.* 1999). In experiments on various films Jacomino *et al.* (2001) found that polyolephenic film with selective permeability showed the best results. This was in spite of affecting the normal ripening of the guavas, the fruits had a fresh appearance and uniform colour, normal flavour and absence of decay, for up to 14 days in storage in 10 °C and 85–90% r.h. followed by 3 days at 25 °C and 70–80% r.h. During this same period, the control fruits became excessively mature and showed a high incidence of decay.

Ripening

After storage in either 5% O₂ + 2.5% CO₂ or 10% O₂ + 5% CO₂ fruits were ripened at 20 °C and 75% r.h. or 28–30 °C and 40–50% r.h. The fruits ripened at 20 °C were ripe in 5 days and those in 28–30 °C in 3 days, but fruits ripened at 20 °C were superior in nutritional and sensory quality to those ripened at 28–30 °C (Pal *et al.* 2007). Ripening was accelerated by exposure to 100 µl L⁻¹ ethylene for 24 h but immature fruit did not ripen properly and developed a gummy texture (Paull and Chen 2002b).

Diseases

Some diseases are associated with damage including *Aspergillus* rot (*Aspergillus niger*), *Mucor* rot (*Mucor hyemalis*), *Phomopsis* rot (*Phomopsis destructum*) and *Rhizopus* rot (*Rhizopus stolonifer*). Orchard sanitation and prompt precooling can reduce incidence (Paull and Chen 2002b). In Yemen Kamal and Agbari (1985) recommended preharvest sprays with either metiram or propineb for control of fruit canker caused by *Pestalotiopsis psidii*. Snowdon (1990) also recommends orchard application of chemical fungicides as well as postharvest fungicidal dips and low temperature storage for *P. psidii* control. Preharvest fungicidal sprays can also control anthracnose caused by *Colletotrichum gloeosporioides* (Pantastico 1975). Qadir and Hashinaga (2001) showed that postharvest fumigation with a mixture of 80% N₂O with 20% O₂ delayed the appearance of disease and reduced the lesion growth rate on inoculated fruit. Mohamed and Saad (2009) evaluated the antagonistic activity of five strains of the yeast *Pichia anomala* against dipoldia rot of guava caused by *Botryodiplodia theobromae*. Their results revealed that *P. anomala* was an effective antagonist against *B. theobromae* *in vitro*. *In vivo* application of *P. anomala* to fruit resulted in the reduction of the disease by up to 50% depending on the strain used.

Gulupa

Passifloraceae

Passiflora pinnatistipula Cav. Other common names include tacso and granadillo de clima frio. It is native

to South America where it is grown in the high Andes between 2500 and 3800 m hence its common name of granadillo of cold climate. It is a woody climbing perennial vine up to 15 m high and produces green fruit maturing to a light yellow or purple that are slightly rounded or oblong and 4–6 cm in diameter. They contain many seeds in a sweet acid pericarp and are eaten fresh or used for juice. They contain phosphorus, calcium, vitamins A, B and C and 1.5% protein (Williams and Buxton 1995).

Palacio (2012) reported on the development of a thin and almost transparent bag combining polyolefin with relatively low amounts of an additive for which a patent is being applied. They carried out storage trials where gulupa fruit packed in 'commercial' plastic bags had a postharvest life of about 30 days, while those in the new bag remained fresh for 50 days. This is in comparison with a postharvest life of 8–10 days for those stored with no packaging. These trials were presumably at Bogotá room temperature of about 25 °C and 40% r.h.

Hawthorne

Rosaceae

Crataegus spp. Tourn. ex L. There are several species of *Crataegus* that produce edible fruit. The common Hawthorne (*C. monogyna* Jacq.) grows wild throughout northern Europe. Another species is the Azarole (*C. azarolus*) whose fruit have an apple flavour and can be used for making jam. In Mexico *C. mexicana* produces edible fruit that are round and slightly flattened, with high nutritive value (Martinez Damian *et al.* 1999). The oldest known living specimen of *C. monogyna* in the United Kingdom is reputed to be more than 700 years old and is located in the churchyard in a village in Norfolk and is called Hethel Old Thorn. Martinez Damian *et al.* (1999) investigated *C. mexicana* fruits (selections San Pablo and Tetela) growing at Chapingo, Mexico. Fruit growth showed a simple sigmoidal pattern, reaching physiological maturity after 165–175 days, with a mean fruit diameter of 3.15 cm, ascorbic acid content of 97.5 mg 100 g⁻¹ and a maximum respiration rate of 90 mg kg⁻¹ h⁻¹. They found that they had a 'medium level' of perishability.

Hog plum

Anacardiaceae

Spondias mombin L., synonymous with *S. lutea* L., also called yellow mombin. It originated in Mexico and there is evidence of its cultivation there in the period 5000–3000 BCE (Purseglove 1975). It is also common in the Amazonian region and has been commercialized throughout Brazil. The fruit is oval in shape, up to 4 cm long and is yellow to orange in colour. It contains a large seed surrounded by a thin layer of watery, juicy aromatic, pleasantly sub-acid, pungent pulp.

Narain *et al.* (2004) reported that the main classes of volatiles in the fruit were esters, alcohols, aldehydes and ketones of which the major components were butyl benzoate (14.8%), citronel acetate (10.8%), 2-methyl-1-propanol (10.3%) and pentanal (8.27%). de Sousa Galvão *et al.* (2011) reported that the principal volatile compounds identified in the ripe umbu fruit pulp were 4-methyl-3-penten-2-one, ethyl benzene, 1-penten-3-one, 2-acetyl thiazole, *p*-xylene, limonene, 2,2-dimethyl 4-octenal, 3-hexanol, 2-nonanol, 1-nonanol, 2-pentanol, 2-octanol, 3-methylethyl 2-butanoate, butyl benzoate, 3-allyl cyclohexene, 2-acetyl furan, 2-hexyl furan, β -caryophyllene and methyl pyrazine. A total of 37 volatile compounds were diagnosed with characteristic aroma attributes. The principal volatile compounds which could be responsible for the characteristic aroma of ripe umbu fruit pulp were β -(Z)-ocimene, methyl pyrazine, 2-butyl-thiophene, methyl octanoate, 2-hexyl furan, 2-octanol, (E)-2-cyclohexen-1-one, 3-bromo-cyclohexene, 1-heptanol, 2-nonanol and 1-octanol.

Huckleberry

Ericaceae

Vaccinium ovatum Pursh. Other common names include California huckleberry, shot huckleberry, winter huckleberry and evergreen huckleberry. It should not be confused with *Solanum intrusum*, which is also called huckleberry. It is native to the western coast of North America in areas from northern California to British Columbia. It is common in

the southern states of the United States, and Mark Twain used the name for his character Huckleberry Finn. In North America, there are approximately 35 species of *Vaccinium*, many of which are known as huckleberries, blueberries or cranberries. In the east and south, huckleberry often refers to plants in the genus *Gaylussacia*, also Ericaceae, of which at least four species produce edible berries. It is an erect, evergreen shrub from 0.5 to 3 m high. The umbel-like bright pink inflorescence emerges from the leaf axils and the fruit are berries that are 6–9 mm in diameter and purplish black in colour. It is similar in appearance to blueberry, but has a tougher skin, a sharper flavour and hard seeds. Harvesting is when they are fully ripe but before they begin to shrivel. Unlike domestic blueberries, huckleberry skins tear when the berries are picked so great care must be taken not to damage them. The torn skins allow juices to leak and promote rotting. They should be refrigerated as quickly as possible after harvest, but no temperature recommendation was given (Barney 1999).

Ilama

Annonaceae

Annona diversifolia Safford, another common name is anona blanca. It is native to Mexico and grows wild in the foothills from the southwest coast to the Pacific coast of Guatemala and El Salvador. The earliest known record of the fruit was made by Francisco Hernandez who was sent by King Philip II of Spain in 1570 to take note of the useful products of Mexico (Morton 1987). The tree grows up to 7.5 m high, often branching from the ground with aromatic, pale brownish grey, furrowed bark with maroon flowers. The fruit is conical, heart-shaped or ovoid globose, about 15 cm long and may weigh up to 0.9 kg. The skin is pale green, pink or purplish with greyish bloom resembling the cherimoya (*A. cherimolia*) but dotted with slightly jutting triangular spikes, although some fruits on the same tree may vary from rough to fairly smooth. The pericarp is tart in flavour and contain up to 80 small seeds. In green varieties the flesh is white and sweet and in the pink or purplish ones it is pink-tinged or all pink. The chemical

Table 109 The composition of ilama fruit from El Salvador for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	71.5 g	Phosphorus	51.7 mg
Protein	0.447 g	Iron	0.70 mg
Fat	0.16 g	Carotene	0.011 mg
Fibre	1.3 g	Thiamine	0.235 mg
Ash	1.37 g	Riboflavin	0.297 mg
Calcium	31.6 mg	Niacin	2.177 mg
		Ascorbic acid	13.6 mg

content was given by Morton (1987) in Table 109. Traditionally, the fruits are not harvested until they have begun to crack open, but they can be harvested a little earlier and held up to 3 days to soften. They will not ripen if harvested too early (Morton 1987).

Indian jujube

Rhamnaceae

Zizyphus mauritiana Lam., *Zyzyphus mauritiana* Lamk., also called ber. It is native to India and widespread there and in the drier parts of Asia and Africa (Purselove 1975). It is cultivated to some extent throughout its natural range but mostly in India where it is grown commercially and has been developed as a crop (Morton 1987). It is a small ever-green tree and their orange to brown skinned fruit are round to oblong shaped drupes that are up to 3 cm long. It has a single hard central stone surrounded by acid pulp of variable thickness, which may be delicious or barely edible depending on the variety. See also Chinese Jujube *Z. jujuba*, which grows in temperate regions. Several cultivars have been selected in India and Chundawat (1990) reported the composition of some of them (Table 110).

Harvesting

The cultivar Zaytoni takes some 120 days from flowering to maturity, but other cultivars can take up to 180 days (Abbas 1997). Maturity is when the first brown spots appear on the skin (Wardlaw 1937). Chundawat (1990) also mentioned that their optimum harvest maturity is when the outer skin has developed a light yellowish scarlet or brownish colour but when they are still crisp. He also reported that under-ripe fruit are acrid and have an unsatisfactory sweetness and over-ripe fruit loose their

Table 110 Composition of the pulp of Indian jujube (source: adapted from Chundawat 1990)

Cultivar	TSS (%)	Protein (%)	Vitamin C (mg 100 g ⁻¹)	Reducing sugars	Total sugars
Gola	19.8	5.25	302	4.75	15.62
Seb	14.2	5.00	190	2.79	12.09
Jogia	17.0	3.50	263	4.41	16.41
Kaithli	14.8	4.12	286	2.74	13.65

attractive colour, become red and loose their crisp juicy texture. Abbas (1997) mentioned that TSS and acidity are the most important criteria used in the Basrah region of Iraq for assessing harvest maturity. He also indicated that in India specific gravity and a change in skin colour to golden yellow are the most suitable methods for judging maturity. Morton (1987) reported that in India, two or three harvests were carried out annually by hand from ladders. The fruits remaining on the tree were shaken down. After wrapping in white cloth, the fruits are put into paper-lined burlap bags holding 50 kg for transport to markets throughout the country.

Prestorage treatments

Hot water treatment at 40 °C was effective in increasing its storage life by slowing ripening and also reduced the rate of ethylene evolution (Anuradha and Saleem 1998). Postharvest dipping of fruits in 0.17% calcium chloride or calcium nitrate solutions extended the shelf life of mature green of the cultivars Umran and Kadaka by 3 days (Panpatil *et al.* 2000).

Postharvest physiology

Abbas (1997) indicated that the fruit was climacteric. He quotes figures for respiration rate at 20 °C as 28 mg CO₂ kg⁻¹ h⁻¹ at harvest progressively rising to 140 mg CO₂ kg⁻¹ h⁻¹ after 8 days then 113 mg CO₂ kg⁻¹ h⁻¹ after 9 days. Ethylene production peaked at 130 µl kg⁻¹ h⁻¹ after 6 days.

Storage

The limiting factors in storage are cracking and wilting. Under ambient conditions of 26–30 °C fruits showed a high degree of disease and loss in colour but could be stored for up to 9 days (Nath and Bhargava

1998). Abbas (1997) indicated that fruit picked at the proper stage of maturity have a storage life of 6–8 days at room temperature, depending on the cultivar. Optimum refrigerated storage recommendations included:

- 0 °C for 45 days with 5 days subsequent shelf life at room temperature (McGuire 1929);
- 4–10 °C for 25–33 days for several cultivars (Abbas 1997);
- 6–8 °C for up to 15 days (Nath and Bhargava 1998).

Modified atmosphere packaging

MA packaging alone had no significant effect on the storage life of fruits at room temperature but packing fruits in sealed perforated plastic bags containing potassium permanganate impregnated chalk sticks was most effective and reduced the rate of ethylene evolution and slowed ripening (Anuradha and Saleem 1998). McGuire (1929) found that at 0 °C in closed containers fruit could be stored successfully for 85 days.

Ripening

Fruits harvested while still green could be ripened to a brown colour with soft sweetish flesh and no off flavours at 21.1 °C in 1000 $\mu\text{L L}^{-1}$ ethylene (Wardlaw 1937). Abbas (1997) found that dipping fruit in 500 mg L^{-1} Ethrel advanced ripening by 6–7 days compared to non-treated fruit. In the latter work there was no indication of the temperature used, also this chemical is not permitted to be used commercially in many countries.

Diseases

In a survey in India Singh and Sumbali (1998) found a total of 32 fungi belonging to 20 genera on Indian jujube fruit. Artificial inoculations in mature jujube fruits with the isolated myco-propagules resulted in most of them causing rot of varying severity. However, *Monodictys castaneae*, *Eupenicillium lapidosum*, *Paecilomyces fumosoroseus*, *Trichurus spiralis* and *Acremonium* spp., although present on the fruit surface, were not able to cause rotting when inoculated. Singh *et al.* (2000) found that 18 different fungal species caused postharvest decay of jujube fruits, but

only *Aspergillus flavus* infection was of significance. Infection resulted in maximum loss of ascorbic acid from the fruit tissues and also induced aflatoxin production during pathogenesis. They noted that approximately 85.7% of the *A. flavus* isolates associated with jujube decay were toxic. Fruit rots were caused by a number of fungal species including *Phoma*, *Colletotrichum*, *Alternaria* and *Pestalotia versicolor*.

Jackfruit

Moraceae

Artocarpus heterophyllus Lam. synonymous with *A. integra* (Thurb.) Merr. and *A. integrifolia* L.f. In Brazil, it is commonly called jaca and two types are identified: jaca-dura (hard jackfruit) and jaca-mole (soft jackfruit). The aroma of the two types is distinctive, and jaca-dura fruit are bigger and harder in comparison with jaca-mole that is often more sweet and aromatic and is also called butter jackfruit (Maia *et al.* 2004, Bicas *et al.* 2011). They grow between latitudes of up to 25° north and 25° south of the equator. Jackfruit is a native of India where it has been cultivated from ancient times from where it was taken from early times by Arab traders to the east coast of Africa. The fruit is used both for cooking as a vegetable in the unripe stage and also as a fresh fruit when ripe (Purseglove 1975).

Trees produce fruit that are a barrel or pear shaped syncarp, which can be up to 90 cm long and 50 cm in diameter and can weigh up to 40 or 50 kg (Figure 94). They have a distinctive yellow skin covered with short hexagonal fleshy spines. The flesh is aromatic, yellow, thick and waxy and since it is propagated by seed the fruit from some trees have a sweet and firm pulp, while those from other trees can be soft and acid. The flesh contains numerous large seeds and a very sticky latex that needs an organic solvent to get it from your hands. The flowers and fruit are formed directly on the trunk and main branches.

In Brazil, Maia *et al.* (2004) reported isopentyl isovalerate (28.4%) and butyl isovalerate (25.6%) as major components identified in jaca-dura, while in jaca-mole isopentyl isovalerate (18.3%), butyl acetate (16.5%), ethyl isovalerate (14.4%), butyl isovalerate (12.9%) and 2-methylbutyl acetate (12.0%) were identified. Rahman *et al.* (1995) reported that the



Figure 94 Jackfruit growing directly on the trunk of the tree in Malaysia.

composition also varied with the maturity stage and climatic conditions with both starch and fibre showing increases as the fruit matured. In ripe jackfruit there was 2% mannitol in firm fruit and 7% of the soft fruit and ribitol was detected in ripe fruit but not in immature fruits. The fruit is also a good source of phenolics and flavonoids (Jagtap *et al.* 2010) and the dominant organic acids were malic acid and citric acid, while succinic acid and oxalic acid were found together with esters as the major compound group contributing to its flavour (Ong *et al.* 2006). They also identified 37 compounds from five cultivars with the main volatile compounds being ethyl isovalerate, 3-methylbutyl acetate, 1-butanol, propyl isovalerate, isobutyl isovalerate, 2-methyl butanol and butyl isovalerate. They concluded that these compounds contributed to the sweet and fruity flavour and aroma of jackfruit. The chemical content was given by USDA in Table 111. The data from Malaysia (Table 112) shows a contrast particularly for moisture content, energy, carbohydrate and vitamin C.

Harvesting

Fruit matures 3–8 months after flowering, and Teao-tia and Awasthi (1968) reported that in north Indian

Table 111 The composition of jackfruit fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	73.46 g	Zinc	0.13 mg
Energy	95 kcal	Total ascorbic acid	13.7 mg
Protein	1.72 g	Thiamine	0.105 mg
Total lipid (fat)	0.64 g	Riboflavin	0.055 mg
Carbohydrate, by difference	23.25 g	Niacin	0.920 mg
Total dietary fibre	1.5 g	Vitamin B-6	0.329 mg
Total sugars	19.08 g	Folate	24 µg DFE
Calcium	24 mg	Vitamin B-12	0.00 µg
Iron	0.23 mg	Vitamin A	5 µg RAE
Magnesium	29 mg	Vitamin A	110 IU
Phosphorus	21 mg	Vitamin E (α-tocopherol)	0.34 mg
Potassium	448 mg	Fatty acids, total saturated	0.195 g
Sodium	2 mg	Fatty acids, total monounsaturated	0.155 g
		Fatty acids, total polyunsaturated	0.094 g

Table 112 Composition of jackfruit pulp for 100 g⁻¹ fresh weight (source: adapted from Tee *et al.* 1997)

Moisture	83.1 g	Phosphorus	26.0 mg
Energy	37 kcal	Iron	1.7 mg
Protein	1.6 g	Sodium	48 mg
Fat	0.2 g	Potassium	292 mg
Carbohydrate	7.3 g	Carotene	110 µg
Fibre	5.6 g	Vitamin B1 (Thiamine)	66 µg
Ash	2.2 g	Vitamin B2 (Riboflavin)	60 µg
Calcium	37.0 mg	Niacin	400 µg
		Vitamin C (ascorbic acid)	7.9 mg

conditions the optimum maturity for harvesting good quality ripe fruit took about 180 days from the date of spike emergence. In other observations fruit growth and maturation normally took 5 months after fruit set but harvesting of immature fruits could take place as early as 4 months. In cooler places and higher altitudes fruit maturation took longer. For culinary purposes tender jackfruits are harvested within 2–3 months after fruit set, before the seeds harden. Harvest maturity is judged to be when the last leaf of the fruit stalk turns yellow, the spines become spaced and yield to moderate pressure, it also develops an aromatic odour and produces a hollow sound when tapped (Pantastico 1975). Similar results were obtained by Selvaraj and Pal (1989) who found that

the fruit is judged to be ready for consumption when it produces a strong ripe fruit flavour, the skin colour, at least in part, changes to yellow and there is a marked change in the pressure required to press the rind of the fruit with a finger.

Harvesting is carried out by cutting the peduncle with a sharp knife and the use of ropes and sickles for fruit located high on the tree that fall into a sack or are lowered by a rope to avoid damage. Jackfruit taste is substandard if harvested from young plants. Old trees are preferred since it is claimed that sweetness and taste increasingly improve with the advancing age of the tree.

Postharvest physiology

Its respiratory pattern led to it being classified as an indeterminate fruit between climacteric and non-climacteric by Biale and Barcus (1970). However, during ripening, the fruit was found by Selvaraj and Pal (1989) to exhibit a typical climacteric pattern of respiration.

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for 3–5 days (Mercantilia 1989). Mercantilia (1989) indicated that it was very sensitive to chilling injury, and Mathur *et al.* (1952) claimed that chilling injury occurred after exposure to 11 °C. Mathur *et al.* (1952) investigated refrigerated storage at seven different temperatures ranging from 0 to 28 °C and at various relative humidity conditions ranging from 55 to 90%. From their study, the optimum storage conditions were 11–13 °C and 85–90% r.h. for about 6 weeks. Other refrigerated storage recommendations include:

- 11.1–12.8 °C and 85–90% r.h. for 6 weeks with 15.6% weight loss (Pantastico 1975);
- 13 °C and 90% r.h. for 1–3 weeks (Mercantilia 1989);
- 13 °C and 95% r.h. for 1–3 weeks (Snowdon 1990);
- 13.3 °C and 85–90% r.h. for 14–45 days (SeaLand 1991).

Simple storage methods were reported by Haq (2006). Farmers store mature fruits in the corner of houses for about a week to ripen and some insert common salt into the pedicel to hasten ripening.

Sometimes farmers dig holes in the ground to store unripe jackfruit.

Diseases

Postharvest diseases include pink disease, *Pellicularia* (*Corticium*) *salmonicolor*, stem rot, fruit rot and male inflorescence rot caused by *Rhizopus artocarp*; and leafspot due to *Phomopsis artocarpina*, *Colletotrichum lagenarium*, *Septoria artocarp* and other fungi. Grey blight, *Pestalotia elasticola*, charcoal rot, *Ustilana zonata*, collar rot, *Rosellinia arcuata*, and rust, *Uredo artocarp*, occur on jackfruit in some regions.

Jamun

Myrtaceae

Syzygium cumini (L) Skeels. Other common names include Java plum, black plum, jambul and Indian blackberry. It is probably a native of Bangladesh, India, Indonesia, Nepal, Pakistan, Sri Lanka and the Philippines and is also grown in other areas of Southeast Asia including Malaysia, Myanmar and also Afghanistan. It is an evergreen tropical tree and is a fairly fast-growing species that can reach heights of up to 30 m and can live for more than 100 years. It is commonly found growing wild and is also cultivated.

The fruit is a berry that is oblong, ovoid and shinning crimson black when fully ripe. Fruits of the grafted varieties are large and deliciously sweet but mildly sour with an astringent flavour. They are accepted to be very good for medicinal purposes especially for curing diabetes because of its effect on the pancreas (Joshi 2001). Composition of the fruit was given by Chowdhury and Ray (2007) as: moisture 83.20, reducing sugar 14.00, crude fibre 0.90, ascorbic acid 0.25, anthocyanin 0.14, ash 0.33, nitrogen 0.13, tannin 1.90 and fat 0.30 g 100 g⁻¹. Several flavonoids, ellagitannins and phenolic acids have been identified in the fruits (Bhatia *et al.* 1971). The fruit also contains jamboline, which is believed to check the pathological conversion of starch into sugar (Chowdhury and Ray 2007).

Fruits were stored in macro-perforated (one and two perforations, 0.3 mm diameter each) and non-perforated PP film bags, 35 µm thick with a bag area of 0.036 m², at 5 °C and 75% r.h. for 23 days.

Sachets containing white silica gel beads were placed inside all the packages to control condensation. Quality of the fruit was maintained in macro-perforated packaging, and the microbiological analysis indicated that the fruits could be stored for long periods in bags with 1 macro-perforation (Rai *et al.* 2011).

Jamaican honeysuckle

Passifloraceae

Passiflora laurifolia L. Other common names include Belle Apple and Water Lemon. It is a native of Central America, the northeastern part of South America and is cultivated from southern Venezuela, Surinam, Guyana and French Guiana down through the Amazon region of Brazil to Peru. It is also naturalized and cultivated in the Caribbean islands and was introduced into Malaysia in the 18th century. It is cultivated there and in Singapore, Thailand and Vietnam. In India, Sri Lanka and Hawai'i it is grown as an ornamental but rarely fruits. Children and adults make a hole in one end of the fruit and suck out the pulp and seeds for refreshment. The juice of the strained pulp makes an excellent beverage (Morton 1987). The perennial climbing vine has longitudinally grooved quadrangular stems, e.g. *P. quadrangularis*. The fragrant flowers are up to 10 cm across with red or purple-red sepals and petals, and it bears oval to ellipsoidal fruit, which are capped with three large green bracts, up to 7 cm long with orange to yellow soft skin and a central cavity filled with seeds and juicy pulp. The pulp contains $1.55 \text{ mg } 100 \text{ g}^{-1}$ of pantothenic acid and the rind $1.87 \text{ mg } 100 \text{ g}^{-1}$. Pantothenic acid belongs to the vitamin B complex group and is sometimes called vitamin B₅ (Morton 1987).

Jamaican sorrel

Malvaceae

Hibiscus sabdariffa L., *H. sabdariffa* var. *sabdariffa*. It is also called sorrel, kirkadi and roselle. Two varieties have been recognized: var. *sabdariffa*, a bushy subshrub that are grown for their calyces and var. *altissima* Wetser a vigorous practically unbranched shrub grows up to 5 m high with fibrous inedible calyces that are grown for its fibres. Purseglove (1968) reported that it is probably a native of West Africa,

although Kennard and Winters (1960) reported that it was from the Old-World tropics and Morton (1987) that it is native from India to Malaysia, where it is commonly cultivated and must have been carried at an early date to Africa. It is now grown throughout the tropical world, and Purseglove (1968) claimed that it was taken by the slave trade to Brazil in the 17th century and was first recorded in Jamaica in 1707 and Morton (1987) that the edibility of the leaves was recorded in Java in 1687 and was being cultivated for food use in Guatemala before 1840. The calyces are infused with boiling water to make a delicious acid drink (mainly citric acid) that is a beautiful red colour similar to cranberry juice. They are also used for making jam. It is the national drink of St Vincent and is a good mixer with rum. A dehydrated powder is produced commercially in the Sudan, which is marketed as Instant Kirkady.

It is a bushy shrub, grows up to 2 m tall, with red or green stems and red or pale yellow inflated edible calyces surrounding the seed pod (Figure 95). The ascorbic acid content was given as only 12 mg in Table 114, while it was given by Fasoyiro *et al.* (2005) as $41.82 \text{ g } 100 \text{ g}^{-1}$ in drinks made from the calyces. The fruit contains about 84.5% water, 12% carbohydrate, 1.7% protein, 1% fat and 4% citric acid (Purseglove 1975). Morton (1987) gave the chemical content and (Busson 1965) their amino acids (Table 113). The chemical content was given by USDA (2012) in Table 114.

The calyces should be harvested some 15–20 days after flowering while they are still tender and fleshy.



Figure 95 Fresh Jamaican sorrel (*Hibiscus sabdariffa*) from the West Indies on the UK market. See colour plate section.

Table 113 The composition of Jamaican sorrel from Guatemala for 100 g⁻¹ fresh weight (source: Morton 1987; adapted from Busson 1965)

From Guatemala (Morton 1987)		Amino acid (μg) (Busson 1965)	
Moisture	9.2 g	Arginine	3.6
Protein	1.145 g	Cystine	1.3
Fat	2.61 g	Histidine	1.5
Fibre	12.0 g	Isoleucine	3.0
Ash	6.90 g	Leucine	5.0
Calcium	1.263 mg	Lysine	3.9
Phosphorus	273.2 mg	Methionine	1.0
Iron	8.98 mg	Phenylalanine	3.2
Carotene	0.029 mg	Threonine	3.0
Thiamine	0.117 mg	Tryptophan	–
Riboflavin	0.277 mg	Tyrosine	2.2
Niacin	3.765 mg	Valine	3.8
Ascorbic acid	6.7 mg	Aspartic acid	16.3
		Glutamic acid	7.2
		Alanine	3.7
		Glycine	3.8
		Proline	5.6
		Serine	3.5

Table 114 The composition of Jamaican sorrel for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.58 g	Potassium	208 mg
Energy	49 kcal	Sodium	6 mg
Protein	0.96 g	Total ascorbic acid	12.0 mg
Total lipid (fat)	0.64 g	Thiamine	0.011 mg
Carbohydrate, by difference	11.31 g	Riboflavin	0.028 mg
Calcium	215 mg	Niacin	0.310 mg
Iron	1.48 mg	Vitamin B-12	0.00 μg
Magnesium	51 mg	Vitamin A	14 μg RAE
Phosphorus	37 mg	Vitamin A	287 IU

The calyces are usually used directly after harvest and no work appears to have been done on their storage. Personal experience is that they can be kept in good condition for considerable periods of time in a domestic refrigerator.

Japanese plum

Rosaceae

Prunus salicina Lindell. It is native to China, but was domesticated in Japan some 400 years ago. The volatile compounds of the cultivars Pioneer, Laetitia and Angeleno were determined during a 7-week storage period including samples from

immature, commercial harvest maturity and tree ripe over two fruiting seasons. A total of 35 compounds were found with 10 of the compounds classified as generic amongst the three cultivars: hexanal, 2-hexenal, hotrienol, linalool, *trans*-linalool oxide, *cis*-linalool oxide, *p*-menth-1-en-9-al, β-damascenone, 2-bornene and α-terpineol. The volatile profiles of all three harvest maturities changed during storage (Louw and Theron 2012).

Harvesting

The cultivar Blackamber should be harvested when they reach a minimum TSS of 10–12% and a TA of greater than 0.70%, because consumers preferred low acidity of TA ≤ 0.6% to high acidity of TA ≥ 0.9–1.0% for the same range of TSS (Crisosto *et al.* 2004). Fruit of the cultivars Angeleno and Autumn Beaut were harvested at both commercial ripeness and tree-ripe and stored at 22 °C and 75–80% r.h. for 10 days by Infante *et al.* (2012). They monitored ripening in a non-destructive way by measuring the absorbance of chlorophyll both on the tree and on postharvest. They found that absorbance of chlorophyll decreased during the last phase of development of the fruit on the tree and this decrease was related to the TSS, flesh firmness and compression strength commonly used for determination of maturity.

Prestorage treatments

Manganaris *et al.* (2008) reported that both the European (*P. domestica*) and Japanese (*P. salicina*) plums respond to 1-MCP by delayed ripening. Postharvest application of 1-MCP at 0, 0.5, 1.0 or 2.0 μL L⁻¹ for 24 h at 20 ± 1 °C to the Japanese plum cultivar Tegan Blue was reported, by Khan and Singh (2007), to delay significantly ethylene production and also suppress its magnitude. Also there was a reduction in the activity of ethylene biosynthesis enzymes and fruit softening enzymes in the skin and pulp tissues. However, subsequently Khan *et al.* (2009) showed similar effects but additionally they reported reduced TSS, ascorbic acid, total carotenoids and total anti-oxidants in the cultivar Tegan Blue that had been treated with 1-MCP compared those not treated. They found that 1-MCP at 1 μL L⁻¹ was effective in extending the storage life up to 6 weeks in cold storage with minimal loss of quality. The

development of chilling injury symptoms during storage at 0–1 °C was significantly reduced through the combination of pretreatment with 1-MCP at 0.6 µl L⁻¹ for 12 h and CA storage in 10% O₂ + 3.8% CO₂ (Singh and Singh 2012a). A method of applying 1-MCP at 0.5 µl L⁻¹ during forced-air precooling on *P. salicina* was described by Minas *et al.* (2013) on the cultivars Yummy Beaut, Black Splendor and Fortune. They found that this treatment followed by storage at 10 °C was a promising new methodology to avoid chilling temperatures and provide considerable energy savings without reducing postharvest life and consumer quality acceptance on plums that had TA of 0.9% or more.

The treatment of the cultivars Autumn Giant and Black Beauty with 500 ppb 1-MCP, alone and combined with MA packing in 30 µm PE film bags, were effective in retarding the timing of the climacteric peaks compared to the control and MA packing alone. They were also effective in reducing the incidence of the flesh browning and softening up to 2 months at 0 °C. The combined treatment was also the most effective in maintaining their quality during subsequent shelf life of 7 days at 20 °C (Erkan and Eski 2012).

Chen and Zhu (2012) treated fruit with aqueous chlorine dioxide at 40 mg L⁻¹ for 10 min combined with 100 W ultrasound for 10 min. These treatments maintained total flavonoids, ascorbic acid, reducing sugars and titratable acids longer than the untreated controls and extended their shelf life to 60 days compared to 35 days for the control. There were no detectable chemical residues in the treated samples. Luo *et al.* (2012) found that prestorage treatment of the fruit with salicylic acid suppressed chilling injury, reduced respiration rate and ethylene production and delayed the onset of the climacteric peak.

Postharvest physiology

Singh *et al.* (2012) reported that cultivars show diversity in climacteric behaviour during ripening. They harvested the cultivars Blackamber (highly climacteric), Amber Jewel (moderately climacteric) and Angeleno (suppressed-climacteric) at commercial maturity and allowed them to ripen at 21 ± 1 °C for 8 days. They found that Blackamber and Amber Jewel showed a faster decline in the enzymatic and non-enzymatic antioxidative systems, parallel to the

faster rate of ripening and senescence as compared to Angeleno. Luo *et al.* (2012) found that chilling injury promoted polyphenol oxidase and peroxidase activities which were associated with fruit flesh browning in the cultivar Qingnai.

Storage

Crisosto *et al.* (2009) recommended 0–5 °C with 80–95% r.h. that delay softening, reduce weight loss and disease incidence, but could result in chilling injury. CA storage at 7.5 °C in 3–5% O₂ + 10–15% CO₂ caused softening and off-flavour after extended storage (Crisosto and Garner 2008, quoted by Minas *et al.* 2013). In contrast chilling injury symptoms during storage at 0–1 °C was significantly reduced through the combination of pretreatment with 1-MCP and storage in 10% O₂ + 3.8% CO₂. In the cultivar Blackamber CA at 1% O₂ + 3% CO₂ or 2.5% O₂ + 3% CO₂ was more effective than MA packaging, which gave an equilibrium gas content of ~10% O₂ and 3.8% CO₂, in retention of flesh firmness and TA during storage at 0–1 °C. Fruit stored in 1% O₂ + 3% CO₂ showed reduced chilling injury and membrane lipid peroxidation after 5 and 8 weeks of storage at 0–1 °C (Singh and Singh 2012a). They concluded that the mode of action of the CA was augmentation of antioxidative metabolism and suppression of oxidative processes.

Jostaberry

Saxifragaceae, Grossulariaceae

Ribes × *nidigrolaria* Rud. Bauer & A. Bauer is from a hybrid of *R. nigrum* × *R. divaricatum* × *R. uva-crispa* or *R. nigrum* and *R. hirtellum*.

Jostaberry is a tetraploid and is the product of a complex breeding programme by Dr R. Bauer of the Max Plank Institute in Cologne and was released to the public in 1977. The bushes are vigorous, upright and spineless. It is resistant to American gooseberry mildew, gall mite and blackcurrant leaf spot.

The shiny black berries are smaller than a gooseberry and a little larger than a blackcurrant and are carried 2–5 on short strigs. They are edible both raw and cooked, are very rich in Vitamin C and make good jam. It has a taste intermediate between a gooseberry and a blackcurrant, with the gooseberry flavour

more dominant in the unripe fruit, and the blackcurrant notes developing as the fruit ripens. Immature fruit can be used in cooking similarly to gooseberries.

Kiwano

Cucurbitaceae

Cucumis metuliferus E. mey. ex. Naud. Other common names include African horned cucumber, horned melon, jelly melon and melano. It originated in the semi-arid regions of southern and central Africa including Botswana, South Africa, Malawi, Namibia, Nigeria and Zimbabwe but mainly around the Kalahari Desert. It is now grown commercially in the New Zealand, Portugal and the United States and was introduced to Australia in the mid-20th century where it became a weed. It is a monoecious, climbing annual herb, with staminate flowers typically appearing several days before pistillate flowers (Morton 1987). The stem is angular, ridged and hairy and at each node a 2–5 cm long curling tendril forms along with two to four pale yellow male flowers, a leaf petiole and occasionally a fruiting branch. The fruit is an indehiscent fleshy berry that is elongated to oval in shape up to 10 cm long and 4–5 cm in diameter. Its skin is thick and is bright golden orange in colour covered with soft spikes or bumps unevenly distributed over the surface giving it a striking and attractive appearance. The pulp is bright green and jelly like containing numerous elongated soft black seeds but otherwise similar to passion fruit. Its flavour is quite bland and somewhat resembles a mixture of banana, lime and cucumber (Romero Rodriguez *et al.* 1992). In mature fruit, fibre content was some 4.0 g 100 g⁻¹ fresh weight. Citric acid was the main organic acid with 0.9 g 100 g⁻¹ fresh weight, and potassium was the main mineral element with 266 mg 100 g⁻¹ fresh weight, but sucrose was not found (Romero Rodriguez *et al.* 1992). The chemical content was given by USDA (2012) in Table 115.

Harvesting

Fruits required about 5 weeks to reach the mature green stage from flowering and another 2 weeks to reach full maturity (Benzioni *et al.* 1993).

Table 115 The composition of kiwano fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	88.97 g	Sodium	2 mg
Energy	44 kcal	Zinc	0.48 mg
Protein	1.78 g	Total ascorbic acid	5.3 mg
Total lipid (fat)	1.26 g	Thiamine	0.025 mg
Carbohydrate, by difference	7.56 g	Riboflavin	0.015 mg
Calcium	13 mg	Niacin	0.565 mg
Iron	1.13 mg	Vitamin B-6	0.063 mg
Magnesium	40 mg	Folate	3 µg DFE
Phosphorus	37 mg	Vitamin A	7 µg RAE
Potassium	123 mg	Vitamin A	147 IU

Storage

It was reported to store very well, and its postharvest life at 20 and 24 °C was found by Benzioni *et al.* (1993) to be at least 3 months, but decay at 20 °C was 30%, while at 24 °C there was no decay. They also reported that fruit stored at 12 °C or lower suffered from chilling injury resulting in high losses within 30 days. Mendlinger *et al.* (1992) found that storage at 5 °C resulted in severe chilling injury that mostly resulted in decay within about 14 days. They also reported that fruits have a very long shelf life and may be kept for several months, but that storage temperature affected fruit shelf life. Shelf life was considerably longer at 20 or 24 °C than at 4, 8 or 12 °C with more than 3 months in 20–24 °C compared with just a few weeks at the lower temperatures. The fruit stored at 12.5 °C showed no important colour change and began to decay within about 2 months. Subsequently fruit were stored at 10, 12.5 or 15 °C and those at 10 °C had severe decay possible because of *Fusarium* and *Alternaria* infections with some decay that began to appear in those stored at 12.5 °C and after 5 months. All fruit at 12.5 °C had decayed. There was no decay on those stored at 15 °C but there was some softening and a change in skin colour from green to yellow-orange. Other refrigerated storage recommendations were 10 °C and 90% r.h. (Snowdon 1990) and 10 °C and 90% r.h. for 180 days (SeaLand 1991).

Ripening

Ethylene treatment was beneficial and may enable the fruit to be harvest at the breaker stage and be stored for a longer period (Benzioni *et al.* 1993).

However, ethylene stimulated colour development from green-yellow to orange at 20 °C but the ethylene-treated fruit were very soft with the gelatinous pulp becoming liquified. Storage at 30 °C for 6 days also increased colour development and caused some breakdown of the internal pulp structure, but not to the same degree as the ethylene treatment (Mendlinger *et al.* 1992).

Diseases

Mendlinger *et al.* (1992) reported postharvest diseases caused by infections with *Fusarium* and *Alternaria*.

Kiwifruit

Actinidiaceae

Actinidia deliciosa (A.Chev.) C.F. Liang et A.R. Ferguson, *A. deliciosa* variety *deliciosa*, *A. chinensis* Planch. The two species are closely related, *A. chinensis* being diploid and *A. deliciosa* hexaploid (Ferguson and Huang 2007). They are also called Chinese gooseberries and yang tao. Ferguson and Huang (2007) reported that seeds of *A. deliciosa* had been taken from China to New Zealand in 1904 and the first commercial kiwifruit orchard was in production by about 1930, and the kiwifruit industry in New Zealand was established on fruit of *A. deliciosa* cultivar Hayward, but recently fruit from *A. chinensis* have become a substantial component of the kiwifruit market (Pranamornkith *et al.* 2012). In fact Ferguson and Huang (2007) reported that *A. chinensis* may have even greater commercial potential than *A. deliciosa* itself. Now about one quarter of all kiwifruit plantings in China are of *A. chinensis*, and this species is also being increasingly cultivated in other countries; in New Zealand, for example, nearly 20% of all kiwifruit orchards were now planted with *A. chinensis*. They also reported that *A. arguta* (Sieb. et Zucc.) Planch. ex Miq., called baby kiwifruit or hardy kiwifruit, shows promise for commercial development. It is a climbing or scrambling plant. The fruit is a berry containing hundreds of small, dark seeds embedded in green flesh. Its skin is usually hairy and light brown in colour. Wang *et al.* (2011) found that butanoates were the main fruity esters in both *A. deliciosa* Hayward and *A. chinensis* Hort16A. They significantly

Table 116 The composition of kiwifruit for 100 g⁻¹ fresh weight. (source: adapted from USDA 2012)

	<i>A. deliciosa</i> Hayward	<i>A. chinensis</i> Hort 16A
Water (g)	83.07	83.22
Energy (kcal)	61	60
Protein (g)	1.14	1.23
Total lipid (fat) (g)	0.52	0.56
Carbohydrate, by difference (g)	14.66	14.23
Total dietary fibre (g)	3.0	2.0
Total sugars (g)	8.99	10.98
Calcium (mg)	34	20
Iron (mg)	0.31	0.29
Magnesium (mg)	17	14
Phosphorus (mg)	34	29
Potassium (mg)	312	316
Sodium (mg)	3	3
Zinc (mg)	0.14	0.10
Total ascorbic acid (mg)	92.7	105.4
Thiamine (mg)	0.027	0.024
Riboflavin (mg)	0.025	0.046
Niacin (mg)	0.341	0.280
Vitamin B-6 (mg)	0.063	0.057
Folate (µg DFE)	25	—
Vitamin B-12 (µg)	0.00	—
Vitamin A (µg RAE)	4	4
Vitamin A (IU)	87	72
Vitamin E (α-tocopherol) (mg)	1.46	1.49
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phylloquinone) (µg)	40.3	5.5
Fatty acids, total saturated (g)	0.029	0.149
Fatty acids, total monounsaturated (g)	0.047	0.036
Fatty acids, total polyunsaturated (g)	0.287	0.207

Samples grown in New Zealand.

increased during ripening, and an extremely high level of butanoates was found in the over-ripe fruit. The chemical content was given by USDA (2012) in Table 116. Total world production in 2010 was estimated by FAO (2013) as 1,388,158 tonnes.

Preharvest treatments

Vines of the cultivar Hayward were sprayed with liquid calcium (Nutrical) at 9.33 L ha⁻¹ on three dates between fruit set and 10 days before harvest. Controlled atmosphere stored fruits from calcium-treated

vines were firmer and of better quality than fruits from other treatment combinations (Basiouny and Basiouny 2000).

Harvesting

In New Zealand optimum harvest maturity of kiwifruit is some 23 weeks after flowering (Pratt and Reid 1974). TSS could be used as a measure of maturity where they should have soluble solids content in the flesh of at least 8% (Pratt and Reid 1974). In subsequent work OECD (1992) stipulated that the minimum soluble solids content should be 6.2% based on the average of 10 sample fruit. A non-destructive technique for assessing the harvest maturity uses a ballistic collision technique (Harvey *et al.* 1995). Fruit are commonly harvested into picking bags by hand (Figure 96). Various handling practices were compared by Bengé *et al.* (2000) who found that harvesting directly into trays, rather than harvesting into bags, transferring them to pallet boxes and packing in a packhouse, did not significantly affect fruit softening during storage.



Figure 96 Kiwifruit harvesting into bags in New Zealand.

Grading

The Organisation de Coopération et de Développement Économiques, Paris published a brochure of standards for kiwifruit. Quality criteria included that they should not be shrivelled and they should be free from sunscald, scars, growth cracks, insect damage, bruises, internal breakdown and decay. They should have at least 14% TSS with flesh firmness of 0.9–1.35 kg force measured with an 8-mm tip (Crisosto *et al.* 1999). Grading is commonly visual, but Clarke (1996) described a machine where there are two cables along which the crop runs. They are made up from high tensile, polyethylene-coated steel. When the crop reaches the prescribed point, ejector bars controlled by solenoid valves and operated by compressed air cylinders push them into a chute. The machine was very gentle to the crop and high drops were unnecessary although padded chutes can be provided.

1-MCP

The application of $1 \mu\text{L}^{-1}$ 1-MCP for 20 h at room temperature immediately after harvest showed beneficial effects in retaining quality during 3 months of storage at 1°C . Those treated with 1-MCP were firmer and had a higher level of TSS than non-treated (Antunes *et al.* 2008a, 2008b). Ascorbic acid was higher in the non-treated fruit but taste panellists did not find significant differences between treatments, except that 1-MCP-treated fruit had better appearance. The *A. chinensis* cultivar Sanuki Gold were harvested between a young stage, 66 days after pollination, and an early commercial harvesting stage, 143 days after pollination. They found that 2 days of exposure to propylene were sufficient to initiate ethylene biosynthesis, while in fruit harvested at commercial harvesting stage, 154 days after pollination, 4 days were required. Treatment of fruit with more than $5 \mu\text{L}^{-1}$ of 1-MCP after the induction of ethylene production subsequently suppressed ethylene production and expression of the ethylene biosynthesis genes for 5 days. These observations suggest that in ripening kiwifruit, ethylene biosynthesis is regulated by a positive feedback mechanism and that 1-MCP treatment at harvest effectively delayed ethylene production by 5 days.

Curing

Curing was reported to be carried out in Italy to reduce rotting during subsequent storage especially rots caused by *Botrytis cinerea* and *Phialophora* spp. It was possible to carry out curing directly in refrigerated rooms, by gradually reducing the temperature from 10 to 0 °C over approximately 10 days. Postponing the establishment of controlled atmosphere storage conditions by 30–50 days avoided its negative impact of increasing *Botrytis* rots, without any adverse effects on fruit firmness (Tonini *et al.* 1999). In New Zealand, curing for at least 48 h has also been reported to reduce the incidence of *Botrytis* rots and development of internal breakdown during subsequent cold storage (Lallu 1997). In Chile, Retamales *et al.* (1997) reported that curing for up to 72 h was beneficial and did not increase softening during subsequent cold storage.

Precooling

Precooling may increase the incidence of *B. cinerea* stem-end rot, low temperature breakdown and physiological pitting and Lallu (1997) concluded that it was preferable not to precool kiwifruits that are predisposed to these disorders.

Respiration rate

The fruit is classified as climacteric, although Zhang (2002) stated it was non-climacteric. In their review, Sfakiotakis *et al.* (1999) found that kiwifruits differ from other climacteric fruits in that they show no increase in ethylene production on the vine nor produce ethylene during cold storage. The fruits show a typical climacteric rise in respiration rate and ethylene production at temperatures of 17–34 °C, while at lower temperatures of less than 11–14.5 °C they behave as non-climacteric fruits. The fruits show thermoregulation of ethylene production separate from the ripening process. Ethylene production was shown to be induced autocatalytically by exposure to exogenous ethylene or propylene, exposure to chilling temperatures, wounding and *Botrytis* infection. Respiration rate was given in Table 117.

Ethylene

Very low levels of ethylene affect the texture of kiwifruit. Arpaia *et al.* (1985) found that kiwifruit

Table 117 Effects of temperature on respiration rate of kiwifruit (source: adapted from Sfakiotakis *et al.* 1999)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	3
4–5	5–7
10	12
20–21	16–22

softened more quickly in levels as low as 0.03 µl L⁻¹ ethylene compared to ethylene-free air at 0 °C. Crisosto *et al.* (1999) reported that as little as 0.005–0.010 µl L⁻¹ ethylene can accelerate softening without affecting other ripening processes, resulting in unripe fruit that are excessively soft. Accumulation of ethylene from wounding or *Botrytis* infection can also cause excessive softening of the fruits in storage (Sfakiotakis *et al.* 1999). Crisosto *et al.* (1999) reported that at harvest maturity (*sic.*), kiwifruit were low producers of ethylene with production rates of approximately 0.1 µl kg⁻¹ h⁻¹ at 0 °C and about 0.1–0.5 µl kg⁻¹ h⁻¹ at 20 °C while ripe fruits it may be 50–100 µl kg⁻¹ h⁻¹. Pranamornkith *et al.* (2012) found that *A. chinensis* cultivar Hort16A was very sensitive to ethylene. There was a loss of firmness with significant differences between fruit stored in 0.001 µl L⁻¹ and 0.1 µl L⁻¹ occurring after 2 weeks of exposure. Fruit exposed to 1 µl L⁻¹ ethylene softened rapidly and also had increased greenness and darkened, which further reduced the quality of this yellow coloured cultivar.

Ethylene absorbents

The cultivar Bruno was stored at –1 °C in sealed PE bags of varying thickness, with and without an ethylene absorbent (Ethysorb). The ripening rate of the fruit and its keeping quality during 6 months of storage and 7 days of subsequent shelf life at 20 °C were compared with those of fruit stored in unsealed 20 µm PE bags. Without ethylene removal from the storage atmosphere, there was no significant effect of the modified atmospheres in the sealed bags on the rate of fruit ripening and no improvement in its keeping quality. However, when ethylene was absorbed from the storage atmosphere, increasing the thickness of the polyethylene bag retarded fruit ripening and, as a result, the CO₂ level within the bags. The postharvest life was extended to 6 months by storing the fruit

at -1°C in sealed 0.04–0.05-mm-thick PE bags containing the absorbent. The average composition of the atmosphere in these bags was 3–4% CO_2 , 15–16% O_2 and less than $0.01\ \mu\text{L L}^{-1}$ ethylene (Ben Arie and Sonengo 1985).

Chilling injury

Lallu (1997) reported chilling injury symptoms for the cultivar Hayward at 0°C as a ring or zone of granular, water-soaked tissue in the outer pericarp at the stylar end of the fruit. Other symptoms may include the development of diffuse pitting and a dark, scald-like appearance on the skin. Exposure of fruits to chilling temperatures for at least 12 days stimulated ethylene production when the fruit were transferred to ambient conditions. However, fruits removed from prolonged storage at 0°C in conventional or controlled atmosphere storage showed reduced capacity to produce ethylene, owing to reduced ACC production and ACC synthase and ACC oxidase activities (Sfakiotakis *et al.* 1999). Low temperature breakdown can affect fruit after several months of cold storage. One of its symptoms was the grainy appearance of the outer pericarp followed by water-soaked areas associated with extreme softening of the fruit (Bauchot *et al.* 1999).

Storage

At room temperature of 20°C and 60% r.h. the fruit could be kept for 7–10 days (Mercantilia 1989). Refrigerated storage recommendations include:

- 0°C and 90–95% r.h. for 2–3 months (Mercantilia 1989);
- -0.5 to 0.3°C and above 94% r.h. (Warrington and Weston 1990);
- -0.5 to 0°C for 2–3 months (Snowdon 1990);
- 0°C and 90–95% r.h. for 28–84 days (SeaLand 1991).

Controlled atmosphere storage

Brigati *et al.* (1989) found that CO_2 above 10% was toxic, resulting in the production of off flavours (Harman and McDonald 1983). Crisosto *et al.* (1999) reported that greater than 7% CO_2 can cause internal breakdown of the flesh. About 10% CO_2 concentrations in storage also reduced the

rate of propylene-induced ethylene production, while reduced O_2 concentrations (1–5%) inhibit propylene-induced ethylene production at the ACC synthesis level (Sfakiotakis *et al.* 1999). Ultra-low O_2 storage inhibited ethylene production by chilling, mainly by destroying the system that converts ACC to ethylene (Sfakiotakis *et al.* 1999) and less than 1% O_2 may induce off-flavours (Crisosto *et al.* 1999). Tulin Oz and Eris (2009) found that storage of Hayward at 0°C and 85–90% r.h. in 2% O_2 + 5% CO_2 retained their quality for 5 months. They recommended harvesting when the TSS content was 5.5–6.5%. Yildirim and Pekmezci (2009) also recommended 0°C and 90–95% r.h. in 2% O_2 + 5% CO_2 for 4 months which suppressed ethylene production and delayed softening. However, they found that there was a slight decrease in vitamin C content in both CA storage and air storage. Steffens *et al.* (2007b) investigated factorial combinations of 0.5, 1.0 and 1.5% O_2 combined with 8, 12 and 16% CO_2 on the cultivar Bruno. Sensory analysis showed that in 1.0% O_2 + 8% CO_2 and 1.5% O_2 + 8% CO_2 fruit stored well without developing off-flavours. Hayward was stored over two seasons in 0–21% O_2 + 0–5% CO_2 at 0 – 10°C . Storage in 5% CO_2 delayed softening but lowering O_2 to near 0% did not inhibit softening completely at 0°C . At temperatures higher than 3°C the additional effect of CA storage was limited (Hertog *et al.* 2004). Zhang (2002) successfully stored kiwifruit at $0 \pm 0.5^{\circ}\text{C}$ in 2–3% O_2 + 4–5% CO_2 with a potassium permanganate absorber for over 180 days. After storage the fruit looked fresh with good colour, smell and taste. The percentage of firm fruit was greater than 92%, and the retention of ascorbic acid was greater than 80% compared to levels at the beginning of storage. Storage at 0°C with 1 week in air and 1 week in air enriched with either 10% or 30% CO_2 reduced fruit softening during storage (Nicolas *et al.* 1989). Other storage recommendations include:

- 0°C and 90–95% r.h. with 5% CO_2 and 2% O_2 (SeaLand 1991);
- 0 – 5°C and 5% CO_2 with 2% O_2 gave excellent results (Kader 1985);
- 3–5% CO_2 and 2% O_2 increase storage life by 30–40% (Brigati *et al.* 1989);
- 0 – 5°C with 3–5% CO_2 and 1–2% O_2 (Kader 1989, 1992);

- 0 °C and 90–95% r.h. in 3% CO₂ and 1–1.5% O₂ maintained fruit firmness during long-term storage, but 1% CO₂ with 0.5% O₂ gave the best storage conditions while maintaining an acceptable level of incidence of rotting (Brigati *et al.* 1989);
- –0.5 to –1 °C at 92–95% r.h. and 4.5–5% CO₂, 2–2.5% O₂ and ethylene at 0.03 µl L⁻¹ or less delayed flesh softening but strongly increased the incidence of Botrytis stem-end rot (Tonini *et al.* 1989);
- 0 °C and either 5% O₂ with 5% CO₂ or 5% O₂ with 2 CO₂, but the shelf life of these fruits was limited to 15 days after 6 months of storage for Hayward in Turkey (Ozer *et al.* 1999);
- 0 °C and 1–2% O₂ + 3–5% CO₂ for 6 months (Crisosto *et al.* 1999);
- 0 °C and 3% O₂ with 10% CO₂ (Basiouny and Basiouny 2000).

Modified atmosphere packaging

Plastic liners are commonly used in boxes of fruits for long distance transport. Mineral powders are incorporated into some films for kiwifruit, particularly in Japan where it was claimed that among other thing, these films could remove or absorb ethylene, excess CO₂ and water (Industrial Material Research 1989, quoted by Abe 1990).

Ripening

Starch was shown to be hydrolysed into glucose and fructose and to a lesser degree into sucrose during ripening (Okuse and Ryugo 1981). Recommended ripening temperatures were 18–21 °C using ethylene at 10 µl L⁻¹ for 24 h in 85–90% r.h. (Wills *et al.* 1989). At either 0 °C or 14 °C Wills *et al.* (2001) found that the time to ripen of the cultivar Hayward increased linearly with logarithmic decrease in ethylene concentration over the range of less than 0.005, 0.01, 0.1 1.0 and 10 µl L⁻¹.

Diseases

Botrytis cinerea, which causes grey mould, may infect the fruit through senescent flower parts, penetrate the fruit directly, or enter through wounds.

Other diseases include blue mould caused by *Penicillium expansum* and phomopsis rot caused by *Phomopsis actinidiae*. Preharvest fungicide treatment, careful harvesting and handling, good temperature management in the store and CA storage helped reduce diseases (Snowdon 1990, Crisosto *et al.* 1999). Ozone treatment at 0.3 µl L⁻¹ to *A. deliciosa*, cv Hayward delayed and simultaneously decreased stem-end rot caused by *B. cinerea* by 56%, while disease severity on infected fruit remained unaffected. Infected fruit formed sclerotia, while no sporulation of the pathogen occurred in the presence of ozone. In subsequent experiments, pre-inoculation exposure of fruit to ozone, at increasing exposure time from 0, 2, 8, 24, 72 and 144 h led to significant suppression of disease incidence, while post-inoculation exposure did not affect it. The observed disease suppression, provided by the pre-inoculation exposure, strongly suggests that ozone treatments induce resistance of kiwifruit to the pathogen (Minas *et al.* 2010).

Physiological disorders

The flesh of immature fruit may soften rapidly and have a water-soaked appearance while the core remains hard and tough, which has been linked with damaging levels of ethylene in combination with 8% CO₂ or higher. Freezing injury usually appears first at the stem end and progresses to the stylar end giving the flesh a somewhat yellow appearance during prolonged storage. Fruit in long-term storage may develop pericarp granulation and/or pericarp translucency especially with ethylene in store and may be simply a consequence of senescence. Distinct white patches of core tissue that are obvious in ripe fruit have also been associated with ethylene and may develop as early as 3 weeks after harvest (Crisosto *et al.* 1999).

Kinnow

Rutaceae

It is commonly referred to as a *hybrid* of *Citrus nobilis* Andrews non Lour. × *C. deliciosa* Frost or simply as *C. deliciosa* Frost. Kinnow was selected and released from the University of California, Riverside,

the United States in 1935 and then introduced to India in 1940 from where it spread to many parts of the Indian subcontinent. They are particularly valued in Pakistan. The trees are highly productive with up to 1000 fruits per tree. The fruit is large, globular in shape with 12–25 seeds per fruit. The factors that have contributed to its success are its golden-orange colour, high juice content and an excellent aroma and flavour (Singh and Sharma 2011).

Harvesting

Sandhu (1992) found that brix : acid ratio was a good index for judging maturity and harvesting is when the fruit's peel becomes orange and they have a brix : acid ratio of 12:1–14:1. The fruit quality was shown to decline in later harvests. Fruits are harvested by clipping the stem with secateurs with the stem cut as short as possible to avoid mechanical injury to the fruit in packing and transport. It has a comparatively loose peel so harvesting by pulling fruits should be avoided as it might tear the skin. In Pakistan fruit were harvested from January to April and ascorbic acid and acidity were higher in early harvested fruit, whereas sugar content and sugar:acid ratios were higher in late harvested fruits (Ahmad 1985).

Storage

Coating kinnow fruits with commercial waxes can increase their shelf life up to 60 days. The fruit can be stored in cold storage at a temperature of 4–5 °C and 85–90% r.h. After 60 days of storage at 5 ± 1 °C and 85–90% r.h. the lowest weight loss was 10.48% in fruits that had been treated with 0.1% a.i. of carbendazim, the second was carbendazim + 1% calcium nitrate (Singh and Sharma 2011).

Modified atmosphere packaging

Packing in 0.03-mm-thick PE film was the most effective method of optimizing storage life. Waxing with Fruitex, Britex561 or Seal Britex-56 and using a 0.03-mm-thick cellophane lining were also effective in reducing weight loss during storage at room conditions of 23–36 °C with 47–77% r.h. as compared to newspaper lining (0.093 mm thick). A problem encountered with PE lining was moisture condensation on the fruit surface that could encourage microbial growth and increase the incidence of rotting.

There did not seem to be any relationship between weight loss during storage and harvest time (Ahmad 1985).

Diseases

Surveys of cold stores in India showed 34–38% postharvest rotting with core rot, stem-end rot, green mould rot and blue mould rot the most destructive rots giving 80–90% of the total postharvest rots. *Alternaria alternata*, *Botryodiplodia theobromae*, *Penicillium digitatum* and *P. italicum* were the most prominent fungi causing more than 60% of the total fruit spoiled. During stored at 5 ± 1 °C and 85–90% r.h. the fruits harvested from the plants that had been treated with chemical or fungicidal sprays exhibited significantly less rotting in comparison to the fruits that had not been treated. Prochloraz was the most effective fungicide and provided complete protection to the fruits from infection for up to 30 days of storage followed by Carbendazim that provided complete protection for up to 15 days of storage. Minimum spoilage of 7.23 was recorded in Prochloraz and 9.45% Carbendazim after 60 days of storage (Sharma *et al.* 2010a). Ahmad *et al.* (2005) recommended postharvest application of Bavistin (0.05%) + packing four fruits in a PE bag, which had the lowest rotting and weight loss. Fruits coated with 100% Sta-Fresh 960 were almost effective. Sharma *et al.* (2010a) also studied indigenous plant extracts in controlling postharvest stem-end rot caused by *Botryodiplodia theobromae*. They found that fruits treated with next-tract of *Allium sativum* at 15% concentration showed significantly less incidence of rotting compared to those that had not been treated or had been treated with other plant extracts. The incidence of rotting was 82.92% for pre-inoculation treatment and 77.47% for post-inoculation treatment. Sharma *et al.* (2012) studied the control of postharvest infection with *Penicillium digitatum* of kinnow fruits using microbial antagonist and found that maximum reduction in rot incidence was observed in fruits treated with spore suspension of *Debaryomyces hansenii* and *Sporidiobolus pararoseus* (KFY-1), where 87.75 and 79.99% in pre-inoculation and 82.60 and 73.33% in post-inoculation treatments were noted, respectively. Spore suspension of *Bacillus subtilis* and *Pseudomonas fluorescens* (Pf-1) were found to be almost as effective.

The aggregate postharvest losses of kinnow from orchards to consumers ranged from 14.87% in the Delhi market to 21.91% in Bengaluru market. The overall postharvest losses for the Delhi market comprised of 2.51% at orchards level, 2.30% during transport and at wholesalers' level and 10.06% at retailers' level. The corresponding losses up to the Bengaluru market were 2.51, 5.70 and 13.7%, respectively (Gangwar *et al.* 2007).

Kumquats

Rutaceae

Fortunella spp. There are two species grown for their fruit; the round kumquat (*F. japonica* [Thunb.] Swing. synonymous with *Citrus japonica* Thunb.) and the oval kumquat (*F. margarita* [Lour.] Swing. synonymous with *C. margarita* Lour.) (Figure 97). They are widely cultivated in Japan and China, and dwarf bushes are given as decorative presents in the Chinese New Year. They look like small oranges and their name in Cantonese, where they are called kam kwat, means golden orange, but they are not true citrus fruits. The whole fruit including the peel is eaten fresh; the peel is sweeter than the pulp. They are also made into jam or candied and used to be exported from China preserved in a sugar solution in jars. It is an evergreen thorny shrub up to 4 m high. The fruit is a berry up to 4 cm in diameter with a pulpy mild edible skin enclosing a sweet acid pulp. They hybridize easily with *Citrus* spp. The chemical content was given by USDA (2012) in Table 118.



Figure 97 Kumquats ready for harvesting in Mexico. See colour plate section.

Table 118 The composition of kumquat fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	80.85 g	Thiamine	0.037 mg
Energy	71 kcal	Riboflavin	0.090 mg
Protein	1.88 g	Niacin	0.429 mg
Total lipid (fat)	0.86 g	Vitamin B-6	0.036 mg
Carbohydrate, by difference	15.90 g	Folate	17 µg DFE
Total dietary fibre	6.5 g	Vitamin B-12	0.00 µg
Total sugars	9.36 g	Vitamin A	15 µg RAE
Calcium	62 mg	Vitamin A	290 IU
Iron	0.86 mg	Vitamin E (α-tocopherol)	0.15 mg
Magnesium	20 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	19 mg	Vitamin D	0 IU
Potassium	186 mg	Vitamin K (phylloquinone)	0.0 µg
Sodium	10 mg	Fatty acids, total saturated	0.103 g
Zinc	0.17 mg	Fatty acids, total monounsaturated	0.154 g
Total ascorbic acid	43.9 mg	Fatty acids, total polyunsaturated	0.171 g

Harvesting

They are produced on small bushes and harvested by hand. They are mature when the fruit has turned from green to orange.

Storage

The fruit could be kept at 20 °C and 60% r.h. for 1 week (Mercantilia 1989). Storage below about 8 °C resulted in chilling injury and caused increased decay (Chalutz *et al.* 1989). Refrigerated storage recommendations include:

- 10 °C and 90% r.h. for 4 weeks (Mercantilia 1989);
- 8–11 °C for several weeks (Chalutz *et al.* 1989);
- 4.4 °C and 90–95% r.h. for 14–28 days (SeaLand 1991).

Langsat, lanzon, duku

Meliaceae

Lansium domesticum Jack. They are also called Chinese gooseberries and yang tao. Langsat, lanzon, duku and longkong are considered separate types of fruit in Thailand because of their different appearance and flavour. Langsat was referred to as *Aglaia*

domestica and longkong, duku nam and duku as *A. dookoo* by Namsri *et al.* (1999), while longkong was referred to as *L. domesticum* by Rattanapong *et al.* (1995). Earlier Prakash *et al.* (1977) referred to the duku and langsat as varieties of *L. domesticum*. They probably originated in the Thai/Malaysian peninsula. The edible portion of the tree is the fruit, which is a berry that is usually borne in clusters from older branches. They are round to oval in shape and vary in size depending on the type and can be up to 4 cm long. They have a thin tough milky skin and translucent, sweet juicy pulp in which also are embedded 0–5 seeds.

Preharvest treatment

Spraying clusters of fruit with 5% calcium chloride, 10 or 11 weeks after fruit set, reduced fruit drop and increased fruit firmness, TSS content and the TSS : TA ratio (Rattanapong *et al.* 1995).

Harvesting

They are considered suitable for harvesting when they have lost their green colour and turned a dull yellow. Over-mature fruits develop brown specks and loose their pubescent bloom, but are said to be of better flavour (Pantastico 1975). In duku, the time taken from floral initiation to anthesis was 7 weeks; ripe fruits were formed 15 weeks after flowering. Only 11% of the flowers normally set fruit, but on bagging the inflorescences at the floral-primordia stage, 21% flowers set fruit (Prakash *et al.* 1977).

Storage

Fruits buried in boxes of sawdust had a shelf life of 7 days in tropical ambient conditions in Trinidad compared to only 3 days for unprotected fruit (Wardlaw 1937), but wastage was high in both cases. Placing fruits in cold storage directly after harvest was said to extend their storage life (Wardlaw 1937). Chilling injury was said to occur when fruits were exposed to temperatures below 10–12.8 °C as brown specs with a water-soaked appearance (Wardlaw 1937, Pantastico 1975). Refrigerated storage recommendations include:

- 12.8–15.6 °C for 13 days with 9.5% loss or 16 days with 50% loss (Wardlaw 1937);

- 11–13 °C and 85–90% r.h. for 14 days (Srivastava and Mathur 1955);
- 14.4 °C in 3% O₂ + 0% CO₂ had 16 days of postharvest life, compared to 9 days for fruit held in air (Pantastico *et al.* 1968);
- 11.1–14.4 °C and 85–90% r.h. for 2 weeks with 24.3% weight loss (Pantastico 1975);
- 11.1 °C and 85–90% r.h. for 14 days (SeaLand 1991);
- 18 °C and 90% r.h. for about 21 days (Piyasaengthong *et al.* 1997)

Controlled atmosphere storage recommendation was 14.4 °C with 0% CO₂ and 3% O₂ extended the storage life from 9 days in air to 16 days (Pantastico 1975). Sealing fruits in PE film bags extended their storage life but resulted in skin browning that was due to CO₂ toxicity (Pantastico 1975). Brown and Lizada (1985) also reported that high CO₂ aggravated skin browning especially combined with 10% O₂ and storage in 0.08-mm-thick PE bags increased surface browning.

Lemons

Rutaceae

Citrus limon (L.) Burm. f. It is native to Southeast Asia and was known to the Arabs in the 10th century who may have introduced it to East and Central Africa. It was introduced to Europe during the 12th or 13th century, and Columbus took it to Haiti on his second voyage in 1493 (Purseglove 1975).

It is a small tree up to about 6 m high. The fruit is called a berry or hesperidium. The chemical content was given by USDA (2012) in Table 119. Total world production of lemons and limes in 2010 was estimated by FAO (2013) as 13,933,864 tonnes.

Harvesting

When the fruit matures it changes from green to yellow. Size is sometimes used to determine when to harvest irrespective of the peel colour (Wardlaw 1937). A common size is 56–57 mm in diameter. The juice content increases as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit, it is possible to specify its maturity. In the United

Table 119 The composition of lemon fruit for 100 g⁻¹ fresh weight (source: USDA 2012)

Water	88.98 g	Thiamine	0.040 mg
Energy	29 kcal	Riboflavin	0.020 mg
Protein	1.10 g	Niacin	0.100 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.080 mg
Carbohydrate, by difference	9.32 g	Folate	11 µg DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 µg
Total sugars	2.50 g	Vitamin A	1 µg RAE
Calcium	26 mg	Vitamin A	22 IU
Iron	0.60 mg	Vitamin E	0.15 mg
		(α-tocopherol)	
Magnesium	8 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	16 mg	Vitamin D	0 IU
Potassium	138 mg	Vitamin K	0.0 µg
		(phyloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.039 g
Zinc	0.06 mg	Fatty acids, total monounsaturated	0.011 g
Total ascorbic acid	53.0 mg	Fatty acids, total polyunsaturated	0.089 g

States the minimum value is 25%. The ratio between TSS and acidity, used with some other citrus fruits, is not important with lemons. They are usually clipped from the tree when the weather conditions are dry to avoid oleocellosis.

Handling

Tariq (1999) in comparison of different types of damage found that scuffing of the peel resulted in the greatest losses. Scuffing resulted in the peel turning brown and *Penicillium* spp. growing on the damaged area. Cuts and bruises were found to be less injurious to fruits than scuffing. Pekmezci (1983) showed that injured or mouldy lemons could generate relatively large amounts of ethylene.

Curing

Davies and Albrigo (1994) quoted 12.5–15 °C with 95% r.h. for curing fruit harvested when they are light green. Sealing in plastic film bags and then exposing them to 34–36 °C for 3 days resulted in the inhibition of *Penicillium digitatum* infection through lignification and an increase in antifungal chemicals in the peel of the fruit (Ben Yehoshua *et al.*

1989b). Sealing the fruit in plastic film before curing was said to be essential to reduce weight loss (Ben Yehoshua *et al.* 1989a). Tariq (1999) found that placing damaged fruits in sealed PE film bags and exposing them to temperatures in the range 25–35 °C for between 3 and 48 h (the lower the temperature is, the longer will be the exposure time required) completely eliminated the browning and fungal growth. The nature of curing appeared to be related only to temperature and humidity since where PE bags were used, the thickness of the film (30 or 50 µm) had no effect on the process, although it changed the O₂ and CO₂ contents around the fruit. Also curing could be achieved without film packaging if the surrounding atmosphere was maintained at 95–98% r.h. (Tariq 1999).

Prestorage treatments

The cultivar Verna harvested at either colour break or uniform yellow, was vacuum-infiltrated with 100 µL⁻¹ gibberellic acid or heat-treated at 45 °C and then stored at 15 °C for 3 weeks. Both treatments increased fruit firmness during storage for both harvest maturities. Gibberellic acid treatment was the most effective in retarding the colour change during storage, especially in the colour break fruits; this was associated with the lowest levels of abscisic acid found in the fruit (Valero *et al.* 1998).

Degreening

When harvested fruit arrive at the packhouse they are graded into fully yellow and those still green or turning. The green or turning fruit may then be degreened. Optimum temperatures for degreening ranged between 25 and 29 °C and humidity as high as possible, generally between 90 and 95% r.h. with ethylene at between 1 and 10 µL⁻¹ for 24–72 h depending on the stage of maturity at harvest and the climate in which they were grown. Degreening of lemons can also be achieved by dipping fruit in 1000 µL⁻¹ Ethrel. This had the same effect as exposing the fruit to 50 µL⁻¹ ethylene gas for 24 h (Amchem information sheet 46). Direct dipping of crops in Ethrel, which are to be eaten, may be governed by food legislation in some countries.

Table 120 Effects of temperature on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{h}^{-1}$) of Eureka lemons (source: adapted from Haller *et al.* 1945)

Temperature ($^{\circ}\text{C}$)	0	4.4	10	15.5	21.1	26.6	32.2	37.7
Respiration rate	3.1	5.2	11.2	15.8	22.7	25.6	40.2	80.5

Postharvest physiology

It is non-climacteric and their respiration rate increased rapidly with increasing temperature as would be expected (Table 120). It has been known for a long time that exposure to ethylene will increase the rate of respiration in lemons (Denny 1924).

Storage

At simulated room temperature of 20°C they could be kept for 1–3 weeks (Mercantilia 1989). Pekmezci (1983) showed that the Turkish cultivar Kutdiken could be stored for 8–9 months at 10°C and 85–90% r.h. Green lemons require slightly higher temperatures than yellow to prevent ethylene build-up. Air flushing to reduce ethylene accumulation in store does not need to be excessive unless a high level of fruit damage is suspected. It will freeze at about -2.3 to -1.9°C (Wright 1942). Other refrigerated storage recommendations include:

- $3-4^{\circ}\text{C}$ and 65–70% r.h. for Italian lemons imported into Russia (Wardlaw 1937);
- $11-14.5^{\circ}\text{C}$ and 85–90% r.h. for 1–4 months for green fruit (Anonymous 1967);
- $0-1.5^{\circ}\text{C}$ and 85–90% r.h. for 3–6 weeks for coloured fruit (Anonymous 1967);
- $0-12.8^{\circ}\text{C}$ and 85–90% r.h. up to 4 weeks for yellow fruit or $11.1-12.8^{\circ}\text{C}$ for longer periods (Lutz and Hardenburg 1968);
- 15°C for up to 4 months after waxing (Anonymous 1968);
- $5.6-7.2^{\circ}\text{C}$ and 85–90% r.h. for 6 weeks (Pantastico 1975).
- $14-15^{\circ}\text{C}$ and 85–90% r.h. for 1–4 months for green fruit (Mercantilia 1989);
- $11-13^{\circ}\text{C}$ and 85–90% r.h. for 3–6 weeks for yellow fruit (Mercantilia 1989);
- $8-12^{\circ}\text{C}$ and 85–90% r.h. for 1–2 months (Hardenburg *et al.* 1990);
- $10-14^{\circ}\text{C}$ and 90% r.h. for 2–5 months for green fruit (Snowdon 1990);

- 11°C and 90% r.h. for 3–6 months for yellow fruit (Snowdon 1990);
- 12.2°C and 85–90% r.h. for 30–180 days (SeaLand 1991);
- $10-12^{\circ}\text{C}$ (Davies and Albrigo 1994).

In spite of some of the recommendations given above, Cohen and Schiffmann Nadel (1978) stated that yellow lemons should be kept above 10°C , as lower temperatures encourage the earlier development of internal browning and peel pitting, especially where the fruit is harvested early. In earlier work Fidler (1963) also showed that green fruit were subject to chilling injury in storage below 12°C , and Anonymous (1968) indicated that chilling injury could occur in storage at 11.1°C . Symptoms were given as pitting and spotting of the skin, staining and darkening of the membranes dividing the pulp segments, water breakdown and off flavours.

Controlled atmosphere storage

The rate of colour change can be delayed with high CO_2 and low O_2 in the storage atmosphere but 10% CO_2 could impair their flavour (Pantastico 1975). Other recommendations include:

- $10-15^{\circ}\text{C}$ with 0–5% CO_2 and 5% O_2 $10-15^{\circ}\text{C}$ (Kader 1985) or with 0–10% CO_2 and 5–10% O_2 (Kader 1989) had a good effect but was not used commercially (Kader 1985, 1992);
- 12.2°C and 85–90% r.h. with 5–10% CO_2 with 5% O_2 (SeaLand 1991);
- $10-13^{\circ}\text{C}$ and 85–90% r.h. with 5–10% O_2 and 0–10% CO_2 for 2–24 weeks (Burden 1997).

Diseases

Lanza *et al.* (1998) worked on the cultivar Femminello Siracusano that had been infected with *Penicillium digitatum* spores. They found that immersion in 10% ethanol at 45°C for 3 min, followed by curing at 32°C for 1 day, or by the application of the yeast *Candida oleophila*, were as effective in controlling disease development as dipping fruits in 1 g L^{-1} a.i. imazalil. Immersion in a 3% solution of sodium carbonate plus hot water treatment at 52°C were also as effective as imazalil treatment against *P. digitatum*. Montesinos-Herrero *et al.* (2011) reported that *P. digitatum* and *P. italicum* were effectively controlled by

fumigation for 6 h at 22 °C with 3000 µl L⁻¹ of ammonia that was injected initially and again 2 h later. This caused the tissue within previously injured areas on the rind of lemons to become darker in colour. However, about 30% of the conidia of *P. digitatum* and 10% of those of *P. italicum* could germinate after 6 h fumigation where two injections of 6000 µl L⁻¹ of ammonia were applied.

Lime berry

Rutaceae

Triphasia trifolia (Burm.f.) P.Wils. synonymous with *Limonia trifolia* Burm. f. and *Triphasia aurantiola* Lour. Other common names include limau kiah, lemondichina and limoncitong kastila. It is native to tropical Southeast Asia specifically Malaysia and the Philippines and has been widely introduced to other subtropical to tropical regions of the world. It has also become naturalized on a number of islands in the tropical Pacific Ocean. *T. trifolia* is a spiny evergreen shrub that grows up to 3 m high. The flowers are hermaphrodite, small, white and fragrant. It produces edible bright red fruit that is a hesperidium up to 1.5 cm in diameter containing two or three small seeds with flesh similar in flavour to sweet lime.

Limes

Rutaceae

Citrus aurantifolia (Christm.) Swingle, *C. latifolia* Tan. It probably originated in the East Indian Archipelago but it was also reported that it grows wild in northern India and may have originated there. It was taken to Europe in the 13th century and to the Americas shortly after European colonization (Purseglove 1975).

It is a small tree that grows up to 5 m high and usually has many short sharp spines. The fruit is a berry or hesperidium, which is non-climacteric. There are two main types of lime, the small diploid type usually called the West Indian or Mexican lime and the larger triploid seedless type, which is known as the Tahiti or Persian lime. The origin of the Tahiti lime is unknown and it has been presumed to be a hybrid of the Mexican lime and citron (*C. medica*). Thompson *et al.* (1974) describes a local Sudanese variety,

Table 121 The composition of lime fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	88.26 g	Thiamine	0.030 mg
Energy	30 kcal	Riboflavin	0.020 mg
Protein	0.70 g	Niacin	0.200 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.043 mg
Carbohydrate, by difference	10.54 g	Folate	8 µg DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 µg
Total sugars	1.69 g	Vitamin A	2 µg RAE
Calcium	33 mg	Vitamin A	50 IU
Iron	0.60 mg	Vitamin E	0.22 mg
		(α-tocopherol)	
Magnesium	6 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	18 mg	Vitamin D	0 IU
Potassium	102 mg	Vitamin K	0.6 µg
		(phyloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.022 g
Zinc	0.11 mg	Fatty acids, total monounsaturated	0.019 g
Total ascorbic acid	29.1 mg	Fatty acids, total polyunsaturated	0.055 g

which is called Baladi, and is the same as the West Indian lime. It had a good strong flavour but was generally smaller than the European market preferred, which is greater than 42 mm diameter. In studies it was found that the distribution of fruit sizes in a commercial harvest was: 8% were greater than 42 mm in diameter, 25% were between 38 and 42 mm in diameter and 67% were less than 38 mm in diameter. Total world production of lemons and limes in 2010 was estimated by FAO (2013) as 13,933,864 tonnes. Oil is also extracted from the peel, which is a major by product of the lime juice extraction industry. The chemical content was given by USDA (2012) in Table 121.

Harvesting

They are commonly harvested when fully grown, but still green. This is judged when the skin loses its irregular bumpy surface, becomes smooth and the peel may turn a lighter shade of green. There are no quality differences between this stage and when fruits turn fully yellow, it is just that many markets prefer limes to be green (Thompson *et al.* 1974). In India the cultivar Kagzi exhibited a sigmoid pattern of growth and took 26 weeks from fruit set to attain harvest maturity (Rao *et al.* 1995). As the

fruit mature their chlorophyll levels are reduced and it is possible to separate limes into different classes on the basis of the chlorophyll levels of the peel, therefore light transmission properties can be used to measure their maturity. With this method it was possible to grade fruits that were indistinguishable by visual examination. A photoelectric machine (ESM model G) was developed by Jahn and Gaffney (1972) for colour sorting citrus fruit including limes.

Prestorage treatments

Limes coated with wax containing 0.1% of either thiabendazole or benomyl remained green and suitable for marketing after 3–4 weeks in hypobaric storage of 170 mm Hg at 21.1 °C (Spalding and Reeder 1976). However, the use of postharvest fungicides is being increasingly restricted. Dipping fruit in kinetin is commonly believed to retain their green colour during storage. Fioravanco *et al.* (1995) dipped Tahiti lime fruits in 25 or 50 $\mu\text{L L}^{-1}$ kinetin for 5 min and found that it did not have any effect on chlorophyll-a or chlorophyll-b content of the peel, which declined throughout storage for 80 days at 7.5–8.5 °C and 80–85% r.h. However, they did find that during 28 days of storage degreening was retarded at 8 or 10 °C compared to ambient conditions. Dipping the fruits in gibberellic acid at 250 mg L^{-1} before storage prevented degreening more than storage at 8 or 10 °C, but the best treatment was gibberellic acid and storage at 10 °C (Mizobutsi *et al.* 2000). Sposito *et al.* (2000) also showed that gibberellic acid treatment at 10, 20, 40, 80 or 160 mg L^{-1} improved green colour retention during storage compared with untreated controls, irrespective of concentration, without any significant effects on internal fruit quality. All the fruits were waxed at 1 L tonne^{-1} then stored at 11 °C and 90–95% r.h. for 45 days followed by 4 days at 25 °C and 70–75% r.h. Gibberellic acid is not a permitted postharvest treatment in many countries. Keleg *et al.* (2003) found that the vitamin C content was highest after 12 weeks of storage of fruits that had been treated with gibberellic acid.

Application of 1-MCP conserved the colour of Tahiti limes at 10 °C during 30 days of storage (Jomori *et al.* 2003). Fruits were treated for 12 h with 0 or 1 $\mu\text{L L}^{-1}$ 1-MCP and then were stored at 5 or 10 °C for 30, 60 and 90 days plus 3 days of simulated marketing at 20 °C. Application of 1-MCP conserved

the colour of stored fruits at 10 °C during 30 days, but chilling injury occurred during storage at 5 °C for 60 days. Win *et al.* (2006) showed that chlorophyllase and chlorophyll-degrading peroxidase activities in flavedo tissue of lime peel were delayed in 1-MCP-treated fruit at concentrations of 250 and 500 nl L^{-1} . 1-MCP at 250 or 500 nl L^{-1} effectively suppressed endogenous ethylene production, but a concentration of 1000 nl L^{-1} accelerated yellowing within 9 days, while 750 nl L^{-1} 1-MCP-treated fruit completely turned yellow in 15 days. Ethylene production rate of fruit that had been treated with 1000 nl L^{-1} 1-MCP was 1.6 times higher than that of non-treated fruit. Also ascorbic acid content was reduced in fruit treated with 1000 nl L^{-1} 1-MCP but not in fruit treated with 250, 500 or 750 nl L^{-1} .

Kaewsuksaeng *et al.* (2012) irradiated mature green *C. latifolia* fruit with UV-B doses at 19.0 kJ m^{-2} and then stored them at 25 °C in the dark. They found that the irradiation effectively suppressed chlorophyll degradation through the control of the action of the chlorophyll-degrading enzyme. However, the ascorbic acid content, with or without irradiation, decreased during storage, but the decrease in those not treated was faster than that had been irradiated. Srilaong *et al.* (2011) found that irradiation of mature green lime fruit (*C. latifolia*) with 8.8 kJ m^{-2} efficiently delayed the decrease of chlorophyll content during storage at 25 °C in darkness.

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for about 2 weeks (Mercantilia 1989). During storage at 5 °C no chilling injury symptoms were observed on Tahiti limes after 30 days but after 60 days 40–58% of fruits showed symptoms and after 90 days all the fruits showed symptoms of chilling injury (Jomori *et al.* 2003). Spalding and Reeder (1976) found that hypobaric storage did not affect chilling injury, but storage in 7% O_2 reduced the symptoms of chilling injury compared to storage in air (Pantastico 1975). Fruit will freeze at about –1.8 to –1.4 °C (Wright 1942). Refrigerated storage recommendations include:

- 7.2 °C and 85–90% r.h. (Wardlaw 1937);
- 9 °C and 85–90% r.h. (El Shiaty *et al.* 1961);
- 8–10 °C and 85–90% r.h. for up to 8 weeks (Anonymous 1967);

- 11.1–12.8 °C and 85–90% r.h. for 8 weeks with 15% weight loss for yellow fruit or 7 weeks with 18% loss for green fruit (Pantastico 1975);
- 9–10 °C and 85–90% r.h. for 6–8 weeks with some loss of green colour after 3–4 weeks for both Tahiti and Key (Hardenburg *et al.* 1990);
- 10 °C and 90% r.h. for 6–8 weeks (Mercantilia 1989);
- 9–10 °C and 90% r.h. for 1–2 months (Snowdon 1990);
- 12.2 °C and 85–90% r.h. for 21–35 days for Persian and Tahiti (SeaLand 1991);
- 12.2 °C and 85–90% r.h. for 42–56 days for Mexican and Key (SeaLand 1991).

Controlled atmosphere storage

Controlled atmosphere storage of Tahiti limes increased decay rind scald and reduced juice content (Pantastico 1975). Other work showed that Tahiti limes stored at 10 °C for 6 weeks in 5% O₂ with 7% CO₂ maintained acceptable green colour, but had low juice content, thick rinds and a high incidence of decay. Those stored in 21% O₂ with 7% CO₂ had acceptable juice content and were considerably greener than limes stored in air. Limes from all treatments had acceptable flavour (Spalding and Reeder 1974). Storage in 10–15 °C with 0–10% CO₂ and 5% O₂ (Kader 1986) or with 0–10% CO₂ and 5% O₂ (Kader 1989, 1992) had a good effect on storage but was not used commercially (Kader 1985). Storage at 12.2 °C with 0–10% CO₂ and 5% O₂ was recommended by SeaLand (1991). Fruits were stored in air or in CA containing 3% O₂ + 3% CO₂, 5% O₂ + 3% CO₂, 3% O₂ + 5% CO₂ and 5% O₂ + 5% CO₂ by Sritananan *et al.* (2006). Those stored in air had higher ethylene production and respiration rate than those in CA. All the CA storage conditions reduced the loss of chlorophyll and change in peel colour compared to fruits stored in air.

Modified atmosphere packaging

A major source of deterioration of limes during marketing is their rapid weight loss. This can give their skin a hard texture and an unattractive appearance. In Sudanese ambient conditions packing limes in sealed PE film bags inside cartons resulted in a weight loss of only 1.3% in 5 days, but all the fruits degreening

more rapidly than to those which were packed just in cartons where the weight loss was about 14% (Thompson *et al.* 1974). However, this degreening effect could be countered by including an ethylene absorbent in the bags (Figure 38). During storage for 80 days at 7.5–8.5 °C and 80–85% r.h. and then for 5 days at 19–26 °C and 55–75% r.h. waxing the fruit and then packing them in PE bags gave better results than waxing or PE bags alone (Fioravanco *et al.* 1995). The combination of hot water dipping + waxing and then packaging in PE bags resulted in the least changes and was the best treatment in maintaining marketable quality, TSS and TA during cold storage (Keleg *et al.* 2003).

Hypobaric storage

Haard and Salunkhe (1975) stated that Tahiti limes could be stored for 14–35 days in cold storage, but this was extended to 60–90 when it was combined with hypobaric conditions. Spalding and Reeder (1974) stored Tahiti Limes in 152 mm Hg pressure for 6 weeks at 10 °C. They showed only small changes in colour, rind thickness, juice content, TSS, total acids and ascorbic acid. Decay averaged 7.8% compared to those stored in air that was 8.3%. Those stored at 228 mm Hg maintained acceptable green colour, but were a slightly lighter green than limes at 152 mm Hg. Those stored in 76 mm Hg maintained acceptable green colour, but had low juice content, thick rinds and a high incidence of decay. Limes from all treatments had acceptable flavour. In subsequent work Spalding and Reeder (1976) found that Tahiti limes retained green colour, juice content and flavour acceptable for marketing and had a low incidence of decay during storage at a pressure of 170 mm Hg for up to 6 weeks at 10 °C or 15.6 °C with 98–100% r.h. Control fruits turned yellow within 3 weeks at normal atmospheric pressure.

Diseases

Thompson *et al.* (1974) found that rotting was generally low during storage, and although levels were higher when fruit were stored in PE bags it did not reach levels that merited the use of a fungicide. *Rhizopus nigricans* was the most common fungus followed by *Penicillium* spp. Native yeast isolates of *Debaryomyces hansenii* were obtained from the pericarp

of Mexican limes and the marine environment by Hernández-Montiel *et al.* (2010). These isolates were effective in controlling *P. italicum* both *in vitro* and by up to 80% during 2 weeks of storage of fruit.

Physiological Disorders

If the fruit are too turgid at harvest, owing to recent rain, irrigation or even early morning dew, some of the oil cells in the peel may be ruptured resulting in the disorder called oleocellosis.

Limequats

Rutaceae

It is a hybrid between lime and kumquat, *Citrus aurantifolia* (Christm.) Swing $\times$ *Fortunella* sp. Swing. The fruit is a berry or hesperidium and has a bright green or yellowish green thin edible skin but they taste like limes and are too sour to be eaten raw. There are other crosses with kumquats including orangequats, a cross between kumquat and orange, and citrangequats, which is a tri-specific hybrid among lime, citron and orange. The purpose of these hybrids appears to be to introduce cold tolerance and dwarfing to the trees. At room temperature of 20 °C and 60% r.h. limequats could be kept about 1 week and at 10 °C and 90% r.h. for 4 weeks (Mercantilia 1989). SeaLand (1991) recommended 10 °C and 90–95% r.h. for 21–28 days.

Litchi

Sapindaceae

Litchi chinensis Sonn., synonymous with *Nephelium litchi* Camb., also called lychee. It is native to the area among southern China, northern Vietnam and Myanmar, but is now cultivated in many countries with tropical and subtropical climates. Numerous wild lychee trees are found in rain forests in Hainan Island from low elevation up to 600 and 1000 m, and below 500 m in hilly areas of the Leizhou Peninsular, west Guangdong and east Guangxi. Wild trees are one of the main species in several of these lowland rainforests. Wild trees can also be found in parts of Vietnam north of Hanoi, although there are fewer pockets of natural rainforests than in China. Wild

specimens are similar in general appearance to some cultivars grown in China and Vietnam and while these fruit are edible, the flesh or aril is relatively thin and sour, and not commercial. Litchi has been taken to most of the tropical and subtropical worlds in the last 400 years. Litchi reached India through Myanmar in 1789, and later on appeared in Bangladesh and Nepal. It has a long history of production in Thailand, but the exact date of its introduction has not been established. It probably arrived from China 150 years ago or perhaps earlier. There are no records of its introduction into the Philippines either, although there is mention of litchi in local literature early in the 20th century. Seeds were sent to Australia in the 1850s, and marcots imported 70 years later (Menzel 2002). There are several cultivars grown in China, the best are large with small seeds, which means that they have a large edible portion. Two such cultivars, which are reported to have a good sweet flavour, are Nuo Mi Ci and Huai Zhi (Huang *et al.* 1990). Fruits were served as imperial tributes in China during the Qing Dynasty between 1644 and 1911. The Bangkok Post of 2 July 2002 reported that a single litchi fruit from a 400-year-old tree that once produced fruit for the Chinese emperors had just sold in an auction in Guangdong province for 555,000 yuan (over US\$60,000 at that time)

It is an evergreen polygamous tree that grows up to 10 m high. The flowers are small and pale greenish yellow produced in large panicles. Fruit contain a single large brown shiny inedible stone or seed. They have a leathery scaly skin enclosing white translucent firm flesh that is sweet and fragrant (Figure 98) (Purseglove 1975). Sivakumar *et al.* (2008) detected four monoterpenic alcohols in litchi fruit with citronellol and geraniol the predominant compounds in the aroma profile and at harvest fruit contained 64.72 mg kg⁻¹ f.w. of citronellol and 148.96 mg kg⁻¹ f.w. geraniol. Significantly lower concentrations of citronellol and geraniol were observed in fruit that had been fumigated with SO₂ + HCl dip treatments. They also reported that limonene, amongst other compounds, was responsible for the citrus aroma in litchi fruit and fruit fumigated with SO₂ or SO₂ + HCl had lower limonene levels. Also, the sesquiterpenes α -curcumene and alloaromadendrene were found to increase slightly in litchi fumigated with SO₂, or SO₂ + HCl dip treatments compared to the ethanol

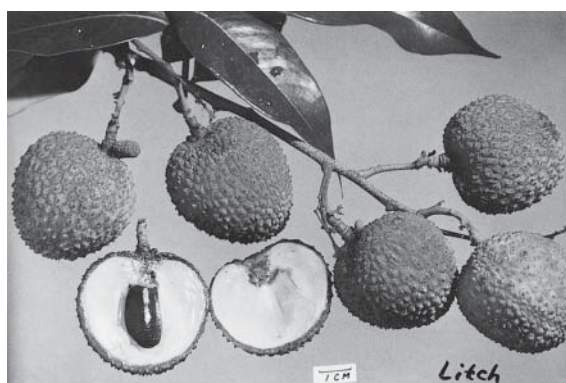


Figure 98 Litchi fruit ready for harvesting, also showing the internal structure. (Photo: Dr Wei Yuqing. Reproduced with permission.)

content increased in fruit during storage due to fermentation especially for late-season fruit stored in MA packages (Pesis *et al.* 2002). Sivakumar (2013) reported that the compounds responsible for spicy aroma were zingiberene and α -curcumene. Alloaromadendrene was responsible for the woody aroma and was found at relatively higher levels in litchis fumigated with SO_2 . Also very strong ethanol smell was detected in SO_2 and $\text{SO}_2 + \text{HCl}$ dip-treated fruit, and it was also moderately pronounced in fruit that had been stored in CA. The chemical content was given by USDA (2012) in Table 122. Huang *et al.* (2005) reported the chemical content of the fruit in Table 123.

Harvesting

The cultivars Dehradun and Seedless took the same number of days (69–72) after full bloom to reach harvest maturity with the cultivar Calcuttia maturing 2 or 3 days later (Muthoo *et al.* 1999). Fruit size can be used for determining the harvest maturity of litchi. In South Africa it was shown that the size of the fruit at harvest could have a very big effect on its profitability during marketing. The longer the fruits were left to mature on the tree, the higher will be the postharvest losses, but even if 70-mm-diameter fruit were harvested and had increased postharvest losses, it may still be economic (Blumenfeld 1993a). In Thailand Reichel *et al.* (2010) found that fruit size and also TA contributed most to the specification of harvest maturity among the seven attributes they evaluated with the cultivars Hong Huey and Chacapat.

Table 122 The composition of litchi fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	81.76 g	Thiamine	0.011 mg
Energy	66 kcal	Riboflavin	0.065 mg
Protein	0.83 g	Niacin	0.603 mg
Total lipid (fat)	0.44 g	Vitamin B-6	0.100 mg
Carbohydrate, by difference	16.53 g	Folate	14 µg DFE
Total dietary fibre	1.3 g	Vitamin B-12	0.00 µg
Total sugars	15.23 g	Vitamin A	0 µg RAE
Calcium	5 mg	Vitamin A	0 IU
Iron	0.31 mg	Vitamin E	0.07 mg
		(α -tocopherol)	
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	31 mg	Vitamin D	0 IU
Potassium	171 mg	Vitamin K	0.4 µg
		(phylloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.099 g
Zinc	0.07 mg	Fatty acids, total monounsaturated	0.120 g
Total ascorbic acid	71.5 mg	Fatty acids, total polyunsaturated	0.132 g

Table 123 The composition of litchi fruit for 100 g⁻¹ fresh weight (source: Huang *et al.* 2005. Reproduced with permission of CABI)

Protein	0.7 g	Thiamine	0.02 mg	Phosphorus	32 mg
Carbohydrate	15 g	Niacin	1.1 mg	Iron	0.7 mg
Vitamin C	15 mg	Riboflavin	0.07 mg	Calcium	4 mg

Precooling

Generally room cooling in a static environment at 2 °C and 80–90% r.h. reduced the pulp temperature close to 2 °C within 13–14 h. However, with 60 m min⁻¹ air speed room cooling at 5 °C and 75% r.h. for 5 h resulted in 0.4% weight loss (Table 124). Bryant (2012) reported a decrease in pre-cooling time to 1 h with an air velocity of 120 m min⁻¹ with a predicted moisture loss of 0.2%. Forced-air cooling was also recommended with humidifiers to maintain about 90% r.h. to reduce desiccation. According to Holcroft *et al.* (2005) forced air cooling with 2.5 cm static pressure difference at 3–5 °C and an 80–90% r.h. took 60 min to achieve the desired pulp temperature. Hydrocooling at 0–2 °C was the most rapid cooling method and reduced the pulp temperature from 30 °C to 2–3 °C within 10–20 min. After hydrocooling fruit must be dried prior to packing and presence of water droplets on the fruit can

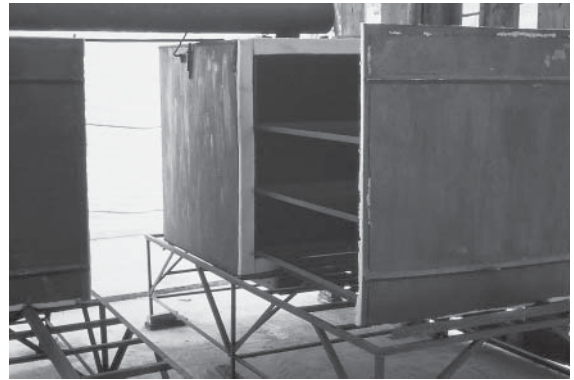
Table 124 Predicted moisture losses under different precooling treatments of litchi fruit (source: adapted from Bryant 2012)

Type of cooling	Temperature (°C)	% r.h.	Air speed (m min ⁻¹)	Duration (h)	Predicted moisture loss
Standard	5	75	60	5	0.38
Forced air	5	75	120	1	0.20
Hydrocooled	5	—	—	1	0

increase subsequent decay development. Litchi fruit hydrocooled at 0–2 °C after harvest, packed in sealed PE bags and stored at low temperatures retained the pericarp colour for a month (Moreuil 1973).

Fumigation

Sulphur dioxide fumigation is used to prevent discolouration of the skins of litchis that is caused by fungal infection. Small simple but effective chambers can be used for this purpose. Fumigation with 1.2% SO₂ for 10 min was shown to be effective in reducing skin discolouration in fresh litchi especially if this was combined a 2-min dip in 1-normality hydrochloric acid (1 N HCl) directly afterwards (Underhill *et al.* 1992). La Ongsri *et al.* (1993) also showed that SO₂ fumigation was an effective treatment, but in this case at 2%, followed by a dip in 1 N HCl to stabilize the red colour and reduce skin browning in the cultivar Hong Huay in Thailand. Tongdee (1993) recommended for the cultivars Honghual and Emperor 5–125 ml SO₂ kg⁻¹ and for the cultivar Khom 125 ml SO₂ kg⁻¹. Holcroft and Mitcham (1996) used SO₂ fumigation by burning 100 g of 90% sulphur powder per m³ at room temperature of 25–28 °C for 20 min with no humidity control. Sauco and Menini (1989) reported that burning 100–150 g of sulphur in a 5 m³ sealed chamber prevented skin browning in litchis. This treatment was only effective for fruit stored for up to 2 weeks. Immediately after SO₂ treatment litchi fruit may appear a uniform yellow colour and then turn red again after 1 or 2 days (Jurd 1964). Milne (1993) described another sulphur treatment of litchi that retained a good postharvest colour. This involves dipping fruit in a sodium metabisulphite solution at 60 g L⁻¹ for 15 min followed by 1 N HCl treatment for 2 min. Liang *et al.* (2012) found that dipping fruits directly after harvest in 60 g L⁻¹ of sodium metabisulphite then 1.1 M HCl effectively delayed

**Figure 99** Small-scale fumigation chamber in use in Thailand for litchis in 1989.

browning and reduced decay during storage at 20 °C and 95% r.h. They also found that after storage the treated fruit had increased anthocyanin content in pericarp tissues and reduced polyphenol oxidase and peroxidase activity compared to those not treated. No sulphur was detected in the aril after dipping although 97.7 mg kg⁻¹ of sulphur residue was found in the pericarp. After storage for 18 days no residual sulphur was detected. Commercial SO₂ fumigation intensified micro-cracking of the pericarp, which would have facilitated SO₂ diffusion and diffusion of HCl into the aril (Sivakumar *et al.* 2005). Small-scale fumigation chambers have been used for litchis for export in Thailand (Figure 99). In a review, Sivakumar *et al.* (2010) reported that EU regulations specify that detectable levels must not exceed 10 ppm and new restrictions on its use by the USA Food and Drug Administration include the requirement that treatment must be declared.

Prestorage treatment

In experiments with the cultivar Huaizhi, a low temperature ‘hardening treatment’ of 5 days at 5 °C prior to storage for 40 days at 1 °C reduced the respiration rate during the latter part of storage. It also delayed increases in cell membrane permeability, browning as well as organic acid and ascorbic acid concentrations. Additionally it reduced the concentration of peroxides in the peel, and extended the shelf life of fruits after removal from cold storage (Zhang and Quantick 2000). Martinez-Castellanos *et al.* (2011) found that spraying a suspension of *Lactobacillus plantarum* on

the cultivar Brewster before storage at 10 °C and 75% r.h. significantly reduced colour losses and retained higher concentration of cyanidin-3-rutinoside and total anthocyanin. Pareek *et al.* (2014) dipped freshly harvested fruit in the biocontrol bacterium *Bacillus subtilis* and allowed them to air dry. They were then placed PP film bags and stored at 2 °C and at 95% r.h. for 20 days followed by 14 °C for 2 days. At market conditions the integrated treatment of the biocontrol *Bacillus subtilis* and PP packaging showed retention of fruit quality of the cultivar McLean's Red by reducing decay and decay-related pericarp browning.

Chitosan coating, a cationic polysaccharide, inhibited the pericarp browning of litchi fruits (Zhang and Quantick 1997). Treating fruit with 20 g L⁻¹ chitosan and storing them in BOPP film completely controlled the pericarp browning in the cultivar McLean's Red, but not completely in the cultivar Mauritius, but there was slight decline in TSS:TA in the aril in both cultivars (De Reuck *et al.* 2009b). Ducamp-Collin *et al.* (2008) also reported that there were differences between cultivars, and Kwai May was better suited for chitosan citric acid treatment than Wai Chee.

Kruger *et al.* (2005) reported that treatment of litchis with 1-MCP followed by storage in MA packaging maintained the quality of the cultivar Mauritius. Sivakumar and Korsten (2007) investigated the possibility of replacing SO₂ fumigation with 1-MCP as a postharvest treatment on the cultivar McLean's Red. They simulated export marketing conditions by fumigation with a moderate concentration of 1-MCP for 3 h followed by storage at 4 °C in 17% O₂ + 6% CO₂ for 21 days then packaging in MA and storage at 10 °C. They found that fungal decay was controlled and their natural pinkish red colour was retained in fruits with these treatments. Those stored in 3% O₂ + 7% CO₂ had a deep red colour but showed limited yeast decay, and the TSS, acidity and ascorbic acid contents were only slightly affected. De Reuck *et al.* (2009a) packed the cultivars Mauritius and McLean's Red in biorientated PP bags and exposed them to 1-MCP at 300, 500 or 1000 nl L⁻¹ within the packaging, heat sealed them and stored them at 2 °C for up to 21 days. This combination of treatments was effective in preventing browning and retention of colour in both cultivars. 1-MCP significantly reduced the PPO and peroxidase activity, retained membrane integrity, anthocyanin content and prevented the

decline of pericarp colour during storage. At higher concentrations than 300 nl L⁻¹ 1-MCP showed negative effects on membrane integrity, pericarp browning, PPO and peroxidase activity in both cultivars, but at 1000 nl L⁻¹ there was a significant suppression of respiration rate and better retention of their TSS, acidity and firmness. Qu *et al.* (2006) reported that dipping fruit in 1 ml L⁻¹ reduced browning and decay control of the cultivar Huaizhi during storage at 28–33 °C and 95–100% r.h. for 6 days. They also reported that the ethylene-treated Huaizhi fruit showed higher activities of phenylalanine ammoni-alyase, POD, PPO and higher browning index suggesting that the pericarp browning of litchi is mediated via ethylene. The decay was linked to the activity of phenylalanine ammonia lyase activity and disease index was low when the PAL enzyme activity was high. Inhibition of PAL in Huaizhi was observed with 1 ml L⁻¹ 1-MCP application. Mauritius and McLean's Red fruit treated with 1-MCP at 500 or 1000 nl L⁻¹ and stored in BOPP film ripened more slowly but had higher pericarp browning after 21 days with subsequent increases in decay (De Reuck *et al.* 2009c). They also had higher PPO and POD activity and higher membrane leakage.

Postharvest physiology

Litchi is classified as a non-climacteric fruit. They have a low rate of ethylene production at less than 1 nl kg⁻¹ h⁻¹ but exposure to ethylene in storage may lead to early aril deterioration. Their respiration rate was given in Table 125.

Anthocyanins in the vacuoles of the pericarp cells are responsible for the red colour of litchi peel. They are affected by acidity, and at a pH of greater than 4, anthocyanin is converted from the flavylium cation to the carbinol form, which is colourless (Underhill and Critchley 1994) hence the hydrochloric acid treatment to reinstate the red colour of the skin after

Table 125 Respiration rate of litchi fruit at different temperatures (source: adapted from Paull *et al.* 2002)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
5	10–16
10	19–29
20	46–74
25	75–128

fumigation. Oxidation of phenolics, the degradation of anthocyanin by the enzymes PPO or POD and the formation of polymeric *o*-quinones can also contribute to pericarp browning (Huang *et al.* 1990, Zauberman *et al.* 1991, Underhill *et al.* 1992, Zhang and Quantick 1997). Underhill and Critchley (1994) concluded that the increase in pH from 4.15 to 4.52 during desiccation could stimulate PPO activity since in intact tissues the PPO is separated from the anthocyanin in the vacuole. Water loss from the fruit caused rapid loss of membrane integrity, bringing the PPO in contact with the anthocyanin (Jiang and Fu 1999, Sun *et al.* 2006). The loss of membrane integrity was also observed to be associated with increased electrolyte leakage after harvest and during storage (Jiang and Fu 1999). The PPO activity was lower than the POD activity (Zhang and Quantick 1997, Ducamp-Collin *et al.* 2008, De Reuck *et al.* 2009a). Duan *et al.* (2004) found that storage of the cultivar Huaizhi for 6 days at 28 °C in 100% O₂ inhibited the activities of PPO and anthocyanase, which reduced pericarp browning and maintained levels of anthocyanins in the pericarp.

Storage

They can be stored at 20 °C and 60% r.h. for 7–10 days (Mercantilia 1989). Storage at 1.1 °C resulted in a loss of brightness (Hatton *et al.* 1966) and suffered from chilling injury (Huang *et al.* 1990). Storage at 0 or 2.5 °C for 3 or 4 weeks also resulted in chilling injury symptoms of dark brown spots appearing on the inner side of the peel. Fruit stored at 5 °C did not show these symptoms, but disease development occurred in fruit stored at 7.5 °C after 4 weeks (La Ongsri *et al.* 1993). Moisture loss in storage was found to be related to browning of the pericarp. A linear relationship was found between air speed and moisture loss over the range tested, from 0 to 1.55 m s⁻¹. A wind speed of 1.55 m s⁻¹ increased moisture loss by a factor of 7 (Bryant 2012). Liu *et al.* (2012) found that there was no pericarp browning of fruit stored at 3–5 °C for 10 or 20 days but fruit stored for 10 days at 3–5 °C gradually browned in 12 h when removed to ambient temperature of 25 °C. Furthermore, fruit stored for 30 days began to rot and had a decay incidence of about 30% after 24 h shelf life. They concluded that the increased activities of lipase, phospholipase D and lipoxygenase, and energy shortage in pericarp tissues

of fruit stored at 3–5 °C during subsequent shelf life at 25 °C suggest that the deterioration of membrane integrity and loss of compartmentation gave rise to accelerated browning and fruit quality deterioration. Reichel *et al.* (2010) stored the cultivars Hong Huey and Chacapat at 5 °C for 21 or 30 days. They found a rapid loss of pericarp moisture and high enzyme activities, mainly peroxidase, accompanied by pericarp browning within 3–5 days. Subsequently, shelf life was chiefly limited by increasing ethanol content of the fruit. Refrigerated storage recommendations include:

- 1.7 °C and 85–90% r.h. for 8–12 weeks (Pantastico 1975);
- 5 °C and 90% r.h. for 4–6 weeks (Mercantilia 1989);
- 1.5 °C and 90–95% r.h. for 3–5 weeks or 7.2 °C for 2 weeks (Lutz and Hardenburg 1968, Hardenburg *et al.* 1990);
- 5 °C for 30–35 days for the cultivars Nuo Mi Ci and Huai Zhi (Huang *et al.* 1990);
- 5–10 °C and 90–95% r.h. for 4–6 weeks (Snowdon 1990);
- 1.7 °C and 90–95% r.h. for 21–35 days (SeaLand 1991);
- 2–5 °C and 90–95% r.h. for 3–5 weeks (Paull *et al.* 2002).

Jiang *et al.* (2003) recommended 1.5 °C for Mauritius grown in Israel, 2 °C for Mauritius and McLeans Red, 3 °C for Heiye, 4 °C for Huaizhi, 5 °C for Kwai May Pink or Gui Wei and 5 °C for Wai Chee or Huai Zhi.

Fruits that had been stored at 5 °C and 90% r.h. (VPD = 0.084 kPa) had a higher concentration of sucrose in cultivars Kom and Mauritius, while lowest concentration of sucrose was during storage at 13 °C and 80% r.h. (VPD = 0.274 kPa). There was also decreasing activity of PPO and POD and reduced respiration rate, reduced changes in TSS:TA ratio and reduced loss of ascorbic acid at the lower temperature (Somboonkaew and Terry 2010). They also found that the storage humidity affected the organic acids in the aril. The highest tartaric acid concentrations were observed in both cultivars at 90% r.h. and concentrations of organic acids were lower in 80% r.h. Storage at 5 °C maintained the malic, tartaric, oxalic and total acids in both cultivars better than those stored at 13 °C. They recommended to control the VPD at

less than 0.068 kPa to attain improved conservation of physiological and biochemical characteristics.

Controlled atmosphere storage

Kader (1993) in his review recommended 3–5% CO₂ combined with 5% O₂ at 7 °C, with a range of 5–12 °C, and that the benefits of reduced O₂ were good and those of increased CO₂ were moderate. Vilasachandran *et al.* (1997) stored the cultivar Mauritius at 5 °C in air or 5, 10 and 15% CO₂ combined with either 3 or 4% O₂. After 22 days all fruit were removed to air at 20 °C for 1 day. Fruits that had been stored in 15% CO₂ with 3% O₂ or 10% CO₂ with 3% O₂ were lighter in colour, retained TSS better than the other treatments, but had the highest levels of off-flavours. All the controlled atmosphere stored fruit had negligible levels of black spot and stem-end rot compared to the controls. On the basis of the above Vilasachandran *et al.* (1997) recommended 5% CO₂ with 3% O₂ or 5% CO₂ with 4% O₂. Mahajan and Goswami (2004) stored the cultivar Bombay at 2 °C and 92–95% r.h. in 3.5% O₂ + 3.5% CO₂ for 56 days. Fruits retained their red colour, while those stored in air had begun to turn brown and a sensory evaluation of aril colour and taste showed that the fruits stored in CA were rated good during the 56 days of storage. Techavuthiporn *et al.* (2006) reported that CA storage in 5% O₂ increased the respiration rate of Hong Huay litchi fruit during long-term storage, whilst 3% O₂ reduced the respiration rate from 63 mg to 25 mg CO₂ kg⁻¹ h⁻¹ during 21 days of storage.

Storage in high levels of O₂ has been shown to have some beneficial effects on litchi fruit and storage in 100% O₂ reduced browning and maintained higher TSS:TA in the aril (Duan *et al.* 2004). Tian *et al.* (2005) found that storage of the cultivar Heiye in 70% O₂ + 0% CO₂ + 30% N₂ for 1 week followed by 5% O₂ + 5% CO₂ + 90% N₂ at 3 °C and 95% r.h. for 14, 24 or 48 days showed significant reduction of decay but browning incidence increased after 14 days. Higher O₂ in storage also limits the PPO and POD activities, which in turn can maintain higher anthocyanin levels to retain the pericarp colour (Tian *et al.* 2005). Also O₂ at 50% showed a significant effect on inhibition of browning in the cultivar Hong Huay for 8 days longer than the ambient temperature, but increased O₂ concentrations up to 70% did not show additional control of browning (Techavuthiporn *et al.* 2006).

Modified atmosphere packaging

Kader (1993) pointed out that modified atmosphere packaging was used to a limited extent. In some cases packing fruit in plastic film was actually detrimental during storage. Fruit were packed in punnets over wrapped with plastic film with 10% CO₂ or vacuum packed and stored for 28 days at 1 °C followed by 3 days shelf life at 20 °C. It was found that skin browning was reduced in both of these plastic film packages compared to unwrapped fruit. However, their taste and flavour were unacceptable, while they remained acceptable for non-wrapped fruits (Ahrens and Milne 1993). Fruits of the cultivar Brewster sealed in LDPE film had the lowest water loss throughout storage at 5 °C, but there was condensation in the internal face of the film. On the other hand, PVC film effectively reduced fresh weight loss, without condensation. Storage at 5 °C reduced pericarp browning, with best results in the PVC film, which delayed browning for 36 days after harvest. In storage at 27 °C, perforated LDPE and PVC films reduced the rate of browning compared to the control, with 16 and 5% incidence of dark fruits 8 days after harvest (Fontes *et al.* 1999). Ragnoi (1989) working with the cultivar Hong Huai from Thailand showed that fruits packed in sealed 37.5-µm PE film bags containing 2 kg of fruit and SO₂ pads could be kept in good condition at 2 °C for up to 2 weeks, while fruits that were stored without packaging were discoloured and unmarketable. Mangaraj *et al.* (2012) developed an MA packaging system that increased the shelf life of litchi by 100–150% of non-packed fruit at various storage temperatures with a quality comparable with freshly harvested fruit. Fruit stored in MA packaging retained quality for up to 17 days at 10 °C, 13 days at 15 °C and 9 days at 20 °C. The packages were 28 × 22 cm made from laminates of BOPP and PVC in order to meet the gas transmission requirements of the fruit and contained 900–1100 g of fruit. Somboonkaew and Terry (2010) stored the cultivar Mauritius at 13 °C for 9 days sealed in different plastic films. During storage concentrations of CO₂ and ethylene were greater in Cellophane WSTM packs followed by NatureFlex NVSTM, PropaFresh PFAMTM and micro-perforated PP films, respectively. Sugars, organic acids in aril and pericarp tissue and individual anthocyanins in pericarp were retained best in the PropaFresh PFAMTM film. These results indicated that PropaFresh

PFAM™ film was the best packaging film to maintain physiological and biochemical properties in litchi fruit.

BOPP film that gave an equilibrium atmosphere of 17% O₂ and 6% CO₂ retained the overall fruit quality of litchi during low temperature storage by reducing pericarp browning, but the effect varied between cultivars, harvest time and infection level (Sivakumar and Korsten 2006a). Tian *et al.* (2005) reported ethanol production in fruit packed in MA packaging with an equilibrium atmosphere of 15–19% O₂ + 2–4% CO₂ for the cultivar Heiye. McLean's Red dipped in hot water at 55 °C for 2 min and then packed in Xtend^(R) or BOPP films showed an increase in CO₂ composition around the fruit with a decrease in weight loss and fruit firmness, lower chroma, higher postharvest decay and browning during low temperature storage (Sivakumar and Korsten 2006a).

The early-season cultivar Mauritius stored in BOPP-3, which gave an equilibrium of 17% O₂, 6% CO₂ and about 90% r.h., reduced the rate of transpiration, weight loss and browning-related enzymatic mechanism and maintained the colour retention and overall fruit quality for up to 21 days at 2 °C and 2 days at 14 °C (Sivakumar and Korsten 2006a). The sensory attributes of Mauritius were not affected by the BOPP-3 packaging, and the panellists did not detect ethanol- or acetaldehyde-related off-flavours. Mauritius had a higher rate of respiration than McLean's Red (De Reuck *et al.* 2009a), which was confirmed by the slightly higher CO₂ concentration within the packaging than McLean's Red. Flushing the punnets with 5% O₂ and 5% CO₂ for both McLean's Red and Mauritius resulted in the optimum concentrations established from the first day of storage (De Reuck *et al.* 2009a). A negative impact on fruit quality can be encountered when the fruit in MA packaging is subjected to postharvest temperature fluctuations (Sivakumar and Korsten 2006b).

Diseases

Disease organisms that have been reported to infect litchi fruit include *Aspergillus* spp. (Roth 1963, Scott *et al.* 1982), *Pestalotiopsis* spp., *Peronophythora* spp., sour rot caused by *Geotrichum candidum*, yeasty rots, *Botryodiplodia theobroma*, *Colletotrichum gloeosporioides* and *Rhizopus oryzae* (Roth 1963, Scott

et al. 1982, Snowdon 1990). Good field sanitation and culling of fruit that show fruit-piercing insects, cracks and sun scorch were effective in minimizing losses (Scott *et al.* 1982). Pareek *et al.* (2014) found that biocontrol treatment with *Bacillus subtilis* and polypropylene packaging of McLean's Red resulted in reduced decay and decay-related pericarp browning after 20 days of storage at 2 °C and 95% r.h. plus 2 days shelf life at 14 °C.

Sivakumar *et al.* (2005) reported that *Penicillium* spp. were among the most dominant decay-causing agents. The litchi pericarp provides an ideal environment for conidial attachment and fungal growth, even during cold storage with the protrusions on the pericarp surface giving it a particularly suitable texture for fungal spores. Following harvesting the microbial population of the phylloplane is altered. *Penicillium* is an opportunistic pathogen that will thrive and develop rapidly on the microbial balance of the fructoplane changes due to postharvest treatment with SO₂ (Korsten 2006). In some litchi-exporting countries the fruit are dipped in hydrochloric acid after SO₂ fumigation in order to regain their red colour. The acidification process creates a niche that is selective for *Penicillium* growth and dominance (Coates *et al.* 2005). The postharvest symptoms of *Penicillium* spp. infection are a blue-green powdery mould growth on the fruit pericarp, followed by softening of the fruit (Coates *et al.* 2005). The predominant *Penicillium* spp. throughout the litchi export chain were identified as *P. expansum*, *P. griseofulvum*, *P. spinulosum*, *P. brevicompactum*, *P. corylophilum*, *P. verrucosum*, *P. aurantiogriseum*, *P. sclerotiorum*, *P. glabrum*, *P. solitum*, *P. citrinum*, *P. chrysogenum* and *P. crustosum* (Johnston *et al.* 2006). They also reported that the presence of *P. verrucosum* and *P. expansum* is of great concern, owing to the ability of these pathogens to produce mycotoxins, such as ochratoxin A and patulin, posing health and safety risks to the consumer.

Physiological disorders

Micro-cracking of the pericarp takes place at the initial stages of fruit development because of the rapid expansion of the aril (Huang and Xu 1983). Drought is another major cause of pericarp cracking during fruit development, which leads to a loss of pericarp extensibility (J.R. Li 2001, quoted

by Joyce *et al.* 2005). Micro-cracking can also be caused during postharvest operations (Sivakumar and Korsten 2004). Litchi cultivars showed similar pericarp development, however, differences in the thickness of cuticle and spongy layers were observed between different cultivars (Huang *et al.* 2004). They also showed that cv. Huaizhi, which had a thicker, spongy layer, showed less desiccation and that the cuticle accumulation pattern might help to explain the susceptibility or resistance to micro-cracking in different cultivars. Differences in wax deposit distribution were observed on the pericarp between the developmental stages of Mauritius and McLean's Red. Commercial SO₂ fumigation and the fluctuation of wet and dry periods at late fruit developmental stages could intensify micro-cracking (Sivakumar *et al.* 2005). The contribution to cracking resistance by calcium is related to its structural role in the cell walls, and the availability of calcium during early fruit development is important for cracking resistance (Huang *et al.* 2005). Huaizhi accumulated more calcium than its physiological needs, and the excess was stored as calcium oxalates, mainly in the epidermis. In contrast, the cultivar Nuomoci stored little calcium oxalate. Owing to the higher concentrations of structural calcium and galacturonans, Huaizhi showed a stronger pectic network, which enhanced cracking resistance. The structural calcium levels decreased in litchi pericarp from 22 to 52 days after anthesis. Cell expansion in the pericarp during this period resulted in the dilution of structural calcium, which eventually increased during aril expansion. This increase in structural calcium could be due to an increased availability of calcium or increased calcium-binding sites in the pectin (Huang *et al.* 2004). The increase in calcium during early stages of fruit development provides a good basis for pericarp development and the final increase in protopectin content in the pericarp guarantees good fruit pericarp quality (Peng and Jiang 2004).

Loganberries

Rosaceae

Rubus loganobaccus L.H. Bailey. It originated in Santa Cruz in California, where it was found growing in

the garden of Judge J.H. Logan in 1881. It is probably a hybrid. The fruit is a collection of drupes and is classified as non-climacteric. They are dull red in colour and more acid than blackberries (*R. ulmifolius*) also the drupes remain tightly adhering to the receptacle even when fully mature.

They are normally harvested by hand with the receptacle in place. When fully mature they have a TSS content of about 10% and a TA of 1.02–3.12% weight for weight (Hulme 1971). Refrigerated storage recommendations include:

- –0.6 to 0 °C and 85–90% r.h. for 5–7 days (Phillips and Armstrong 1967);
- –0.6 to 0 °C and 90–95% r.h. for 2–3 days (Lutz and Hardenburg 1968);
- –0.5 and 90–95% r.h. for 2–3 days (SeaLand 1991).

Longan

Sapindaceae

Dimocarpus longan (Lour.) Steud., synonymous with *Euphoria longan* (Lour.) Steud., *Euphoria longana* Lam. and *Nephelium longana* Cambess. There is some confusion in the taxonomy and common names given by different authors for similar fruits in Southeast Asia:

- Duko Nam, *Aglaia dookkoo* by Namsri *et al.* (1999) and Chantaksinopas and Kosiyachinda (1987).
- Duku A. *dookkoo* by Namsri *et al.* (1999) and Chantaksinopas and Kosiyachinda (1987) and varieties of *Lansium domesticum* by Prakash *et al.* (1977).
- Langsat, *Aglaia domestica* by Namsri *et al.* (1999) and varieties of *L. domesticum* by Prakash *et al.* (1977).
- Lanzon, *L. domesticum* Correa by Pantastico *et al.* (1968) and Brown and Lizada (1985).
- Longan (*Dimocarpus longan* (Lour.) Steud.) by Nakasone and Paull (1998) and *D. longan* Lour. by Jiang *et al.* (2002).
- Longkong A. *dookkoo* Griff., A. *dookkoo* by Namsri *et al.* (1999) and Chantaksinopas and Kosiyachinda (1987), A. *dookkoo* by Piyasaengthong *et al.* (1997), *Lansium domesticum* Jack by Rattanapong *et al.* (1995), *L. domesticum* Correa by Pantastico *et al.* (1968) and Brown and Lizada (1985),

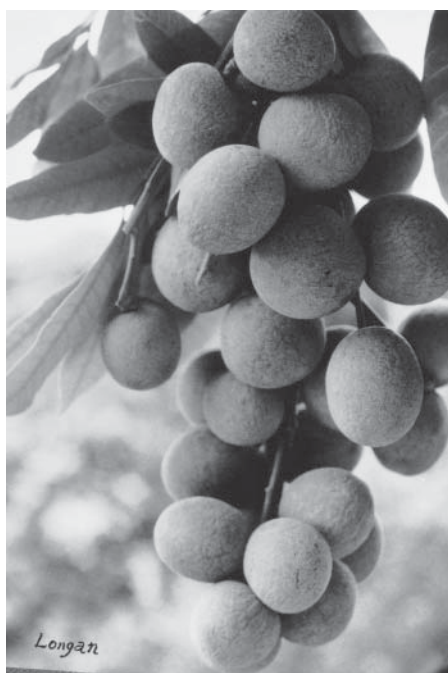


Figure 100 Longan ready for harvesting in China. (Photo: Dr Wei Yuqing. Reproduced with permission.)

A. dookoo by Namsri *et al.* (1999) and *L. domesticum* by Rattanapong *et al.* (1995).

Its origin was probably in the area from Myanmar to south China. It is native to southern China, in the provinces of Kwangtung, Kwangsi, Schezwan and Fukien, between elevations of 150 and 450 m. The fruit are produced on evergreen trees that are more vigorous than litchi (*Litchi chinensis*). The fruit are borne on panicles or bunches and are ovoid berries and can be up to 2 cm long (Figure 100). The fruit is similar to litchi but is light brown or it may be red to orange yellow in colour with a smooth skin. It has a large central brownish-black seed surrounded by a thin layer of sweet translucent pulp. The chemical content was given by USDA (2012) in Table 126.

Preharvest treatments

They are harvested over a 4–6 week period in mid-summer (Menzel 1989). However, with this short harvest period growers have used chemical treatments to extend the fruiting season including

Table 126 The composition of longan fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	82.75 g	Phosphorus	21 mg
Energy	60 kcal	Potassium	266 mg
Protein	1.31 g	Sodium	0 mg
Total lipid (fat)	0.10 g	Zinc	0.05 mg
Carbohydrate, by difference	15.14 g	Total ascorbic acid	84.0 mg
Total dietary fibre	1.1 g	Thiamine	0.031 mg
Calcium	1 mg	Riboflavin	0.140 mg
Iron	0.13 mg	Niacin	0.300 mg
Magnesium	10 mg	Vitamin B-12	0.00 µg

a soil drench with the herbicide potassium chlorate (Subhadrabandhu and Yapwattanaphun 2001, Jiang *et al.* 2002).

Harvesting

It takes some 20–28 weeks from fruit set to fruit maturity. In Chiang Mai, Thailand the harvest season is between late June and August, and all the fruit on one tree are normally harvested at the same time (Tongdee 1997). Fruit size and weight were consistently shown to have a high correlation with eating quality (Onnop *et al.* 1993) and are used to determine harvest time. Tongdee (1997) indicated that TSS could be used to determine harvest maturity using 15.5–16 °Brix. Harvesting is carried out by climbing the trees or using ladders. The bunches are collected in baskets which are then lowered to the ground (Figure 101).

The fruit are packed in the plantation in baskets or boxes still in bunches (Figure 102). Tongdee (1997) mentioned that fruit are graded by size for the market with the top grade, 55–75 fruits per kilogram, being the best grade, and smaller fruit being considered to be of lower grade. She also indicated that the other factors related to quality are 'length of stalk, colour of rind, freedom of fruit from blemishes, rotting or apparent insect damage, and percentage of loose fruit'.

Prestorage treatments

Pretreatment with various chemical is used directly after harvest to reduce pericarp browning including ozone, oxalic acid, citric acid (Whangchai *et al.* 2006) and *N*-acetyl-L-cysteine (Sodchit *et al.* 2008).



Figure 101 Longan harvesting using ladders with the fruit lowered to the ground in baskets in Thailand.



Figure 102 Packing longans into plastic boxes in Thailand for export to Malaysia and Singapore.

Hai *et al.* (2011) reported that soaking the cultivar Long in 7.5% sodium metabisulphite solution for 10 min maintained their colour and reduced PPO activity during 21 days of storage at $5 \pm 1^\circ\text{C}$ in 35- μm -thick polypropylene bags containing 1 kg in each bag.

Postharvest physiology

Tongdee (1997) and Jiang *et al.* (2011) reported that the fruit was non-climacteric and that their respiration rate was $10\text{--}16\text{ ml CO}_2\text{ kg}^{-1}\text{ h}^{-1}$ at 22°C and $2\text{--}6\text{ ml CO}_2\text{ kg}^{-1}\text{ h}^{-1}$ at 5°C and ethylene production from undetectable to trace. Paull and Chen (1987) reported that their ethylene production was less than $1\text{ nl kg}^{-1}\text{ h}^{-1}$ and their respiration rate was $3.5\text{--}11.3$ at 5°C , $16\text{--}25$ at 10°C and $30\text{--}53\text{ mg CO}_2\text{ kg}^{-1}\text{ h}^{-1}$ at 20°C .

Storage

They have a postharvest life of 3–4 days at ambient temperatures (Jiang *et al.* 2002). With the cultivars Shixia and Wuyuan, grown in Guangzhou in China, storage at 1°C resulted in chilling injury on the skin of Wuyuan, which increased rapidly after 20 days. Wuyuan appeared to be more chilling sensitive than Shixia. Tongdee (1997) in Thailand found that chilling injury occurred during storage at $5\text{--}7^\circ\text{C}$ for 3–4 weeks as browning of the skin and increased fungal growth when removed to ambient temperatures. Refrigerated storage recommendations include:

- $4\text{--}7^\circ\text{C}$ and 90–95% r.h. for 2–3 weeks although the skin lost its yellowish colouration and became brown (Paull and Chen 1987);
- 4°C and 90% r.h. (Snowdon 1990);
- 1.7°C and 90–95% r.h. for 21–35 days (SeaLand 1991);
- 1°C for the cultivar Shixia (Jiang *et al.* 1999);
- 2.5°C for the cultivar Wuyuan (Jiang *et al.* 1999);
- 2°C and 90% r.h. (Jiang and Li 2001);
- $1\text{--}5^\circ\text{C}$ for about 30 days reduced pathological decay, but had only a limited role in reducing pericarp browning (Jiang *et al.* 2002).

Jiang *et al.* (2002) also reported that fruit deteriorated rapidly when removed from cold storage. Suwanagul (1997) reported that their storage life was considerably extended with SO_2 treatment (Table 127).

Controlled atmosphere storage

Tongdee (1997) found that controlled atmospheres had no extra benefit on storage life compared to

Table 127 Storage life of longan, in days, in high humidity at different temperatures with and without SO₂ treatment (source: adapted from Suwanagul 1997)

Temperature (°C)	No SO ₂ treatment	SO ₂ treated
0	14–28	21–42
4	14	14–28
10	7–14	14
20	3–5	7
30	1–2	3–5

cold storage in air. However, in China storage of the cultivar Shixia at 1 °C with 6–8% CO₂ and 4–6% O₂ gave the best disease control and fruit quality maintenance (Jiang *et al.* 1999).

Diseases

Fungi associated with postharvest diseases of fruit include *Glomerella cingulata* (Stonem.) Spauld. & Schr. (Anthracnose), *Aspergillus* spp., *Botryodiplodia* spp., *Phytophthora palmivora* E.J. Butler, *Pseudoperonospora* spp., *Phomopsis longanae* Chi & Jiang and *Marssonina euphoriae* C.F. Zhang & P.K. Chi. (CABI 2003, DOA 2003). For the cultivars Do and Biew Kew, Tongdee (1993) recommended fumigation with SO₂ at 200–300 ml kg⁻¹ of fruit as soon as possible after harvest. She subsequently reported that excessive exposure to SO₂ can damage fruit causing irregular rusty brown circles or lines on the underside of the skin and eventually increased fungal growth (Tongdee 1997). Whangchai *et al.* (2006) reported that exposure of the cultivar Daw to 200 µl L⁻¹ of ozone for 1 h reduced their microorganism population on fruit surfaces immediately after fumigation and for 3 days in storage at 25 °C, but exposure for 2 h increased disease incidence. They also found that treatment with oxalic acid or citric acid reduced browning and they commented that the combination of ozone and oxalic acid or citric acid 'could be a partial alternative to sulphur dioxide fumigation as a control of postharvest decay and browning.' Sodchit *et al.* (2008) found that treatment of the cultivar Daw with *N*-acetyl-L-cysteine prevented pericarp browning, which resulted in better colour during 6 days of storage at 15 ± 2 °C and 85% r.h. Treated fruit also tended to have decreased disease incidence and lower weight loss.

Longkong

Meliaceae

Longkong, duku nam and duku are referred to as *Aglaia dookkoo* Griff. by Namsri *et al.* (1999) and Chantaksinopas and Kosiyachinda (1987) and Piyasaengthong *et al.* (1997) referred longkong as *A. dookoo*, but Rattanapong *et al.* (1995) referred longkong as *Lansium domesticum* Jack. and Pantastico *et al.* (1968) and Brown and Lizada (1985) as *Lansium domesticum* Correa.

The Thai/Malaysia peninsular through to Borneo and the Philippines are the major areas of cultivation. Other areas of cultivation include Australia, India, Myanmar, Puerto Rico, Sri Lanka, Surinam and Vietnam. It is a tropical tree. The fruit is a berry borne in clusters and has a similar appearance to langsat but is larger in size and has a distinct flavour. Chantaksinopas and Kosiyachinda (1987) found that over 95% of fruits had five carpels.

Harvesting

The growth curve from fruit set until maturity was single sigmoidal, and the growth period lasted 14 weeks. The fruit shape during the growth period up to 13 weeks was global and changed to spherical a week later. The rind thickness increased after fruit set until the 9th week, and then decreased slightly until maturity. The percentage of soluble solids in fruit juice increased gradually until week 14 with a maximum of 17%. Acid quantity decreased until the fruit became mature with 1% of titratable acids in week 15. TSS:TA ratio in week 15 was 18.1. Harvesting is recommended during 14–16 weeks after fruit set (Chantaksinopas and Kosiyachinda 1987). Bioassay-guided fractionation of stems and fruits of *A. elliptica* from Thailand showed that the compounds were very potent cytotoxic substances when evaluated against a panel of human cancer cell lines (Cui *et al.* 1997). Extracts from the fruit of another species, *A. roxburghiana*, were also shown to have medical uses.

Preharvest treatment

The effect of calcium chloride at 0, 3 or 5%, applied 9, 10 or 11 weeks after fruit set, on the quality of *L. domesticum* fruits was evaluated. Treatment of

clusters with 5% calcium chloride, 10 or 11 weeks after fruit set, reduced fruit drop and increased fruit firmness, TSS content and the ratio of TSS:TA Ratatanapong *et al.* (1995). Taesakul *et al.* (2012) found that dipping fruit in 200 $\mu\text{L L}^{-1}$ NAA solution delayed fruit abscission, slightly reduced ethylene production and reduced the effect of endogenous ethylene exposure. Applications of 1 $\mu\text{L L}^{-1}$ 1-MCP for 6 h also minimized the effect of endogenous ethylene and almost doubled their storage life, but the combination of NAA and 1-MCP treatment did not give a synergistic effect. Lichanporn and Techavuthiporn (2013) found that fruit treated for 3 h with nitrous oxide vapour had delayed browning and reduced activity of enzymes associated with browning in longkong pericarp.

Postharvest physiology

Respiration rates were given as 40–50 at 9°C and 50–90 $\text{mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 20°C, but rates declined during storage, and small fruit had a higher respiration rate than larger fruit. Fruit produce low amounts of ethylene, with internal concentrations of 2–6 $\mu\text{L kg}^{-1}$ (Srivastava and Mathur 1955, Pantastico *et al.* 1968). The fruit are marketed in clusters. There is a clear abscission zone between the main peduncle and the calyx and exposure to ethylene at concentrations as low as 0.05 $\mu\text{L L}^{-1}$ induced abscission in this area (Taesakul *et al.* 2012). Abscission of the berries can affect their market value. Lichanporn *et al.* (2009) showed that ethylene treatment markedly increased peel browning, and the ultrastructure of the peel surface collapsed after harvest especially around brown areas during storage at 25°C and 70–85% r.h. The total phenolic content of peel tissue rapidly increased, concomitant with rapid increases in phenylalanine ammonia lyase (PAL) activity and browning by the second day of storage.

Storage

Symptoms of chilling injury developed after 21 days at 15°C as skin browning (Piyasaengthong *et al.* 1997) so they recommended 18°C and 90% r.h. for up to 21 days. However, other storage recommendations were 11–14.4°C and 85–90% r.h. for 2 weeks with 24.3% weight loss (Pantastico 1975) and 11–13°C and 85–90% r.h. also for 2 weeks (Srivastava and Mathur 1955).

Controlled atmosphere storage

Fruit stored at 14.4°C in 3% O_2 + 0% CO_2 had 16 days of postharvest life, compared to 9 days for fruit held in air (Pantastico *et al.* 1968).

Modified atmosphere packaging

Fruits stored in 0.08-mm-thick PE film bags had increased surface browning possibly because of high CO_2 that can occur in fruit held in PE film bags particularly at the high storage temperatures of 10% or more (Brown and Lizada 1985).

Loofah

Cucurbitaceae

Luffa acutangula L. Roxb. Other common names include angled luffa, dishcloth, kalitori, luffa, Chinese okra, gourd, ridge gourd and towel gourd. It originated in India and is cultivated in the tropics for its tender edible fruits particularly in India and also in Indonesia, Malaysia, Myanmar, the Philippines, Sri Lanka and Taiwan. The green, immature fruit is eaten as a vegetable (Figure 103), but mature fruit are allowed to dry and are mainly used for cleaning and scrubbing. It is an annual climber with tendrils and is monoecious but hermaphrodite, andromonoecious and gynoeceous flowers also exist. The fruit are club shaped with 10 longitudinal ridges and contains many seeds. The chemical content was given by USDA (2012) in Table 128.

Fruit for consumption are harvested immature. If they are left to mature the blossom-end enlarges and the stem-end shrinks and they become bitter (Zong *et al.* 1993). The fruit produce very low levels of ethylene at less than 0.1 $\mu\text{L kg}^{-1} \text{ h}^{-1}$ at 20°C but they are sensitive to ethylene and exposure to 10 ppm resulted in accelerated loss of green colour and ripening-related changes. Their respiration rate was reported in Table 129. Fruit are sensitive to chilling at less than 10°C, the symptoms include skin discolouration, watery lesions under the skin and increased decay. Quality loss is most often associated with loss of green colour. They can be stored at 10–12°C and 90–95% r.h. for up to 2 weeks (Zong *et al.* 1992, 1993).



Figure 103 Chinese okra (*Luffa acutangula*) on sale in Californian market. See colour plate section.

Loquat

Rosaceae

Eriobotrya japonica L., also called Japanese Medlar. Loquat originated in mid to western China and is widely cultivated in the subtropical regions of southern China, Japan, Mediterranean area, Hawai'i, California and the Gulf States. It is a subtropical evergreen tree. Fruits grow in loose clusters and are ovoid or pear shaped, up to 8 cm long and weigh about 20–80 g with a pale orange or light yellow skin. The skin is thin but tough and flesh is yellow to light orange and may contain up to 10 seeds. Ding *et al.* (1998) reported that fructose, glucose and sucrose were the dominant sugars and sorbitol was a minor one in the cultivar Mogi. The chemical content was given by USDA (2012) in Table 130.

Harvesting

Hamauzu *et al.* (1997) described eight stage of harvest maturity from stage 1 (green, small) to stage 7 (yellowish orange) and stage 8 (slightly over ripe)

Table 128 The composition of gourd, dishcloth (towel gourd) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	93.85 g	Total ascorbic acid	12.0 mg
Energy	20 kcal	Thiamine	0.050 mg
Protein	1.20 g	Riboflavin	0.060 mg
Total lipid (fat)	0.20 g	Niacin	0.400 mg
Carbohydrate, by difference	4.35 g	Vitamin B-6	0.043 mg
Total dietary fibre	1.1 g	Folate	7 µg DFE
Total sugars	2.02 g	Vitamin B-12	0.00 µg
Calcium	20 mg	Vitamin A	410 IU
Iron	0.36 mg	Vitamin E	0.10 mg
		(α-tocopherol)	
Magnesium	14 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	32 mg	Vitamin D	0 IU
Potassium	139 mg	Vitamin K	0.7 µg
		(phylloquinone)	
Sodium	3 mg	Fatty acids, total saturated	0.016 g
Zinc	0.07 mg	Fatty acids, total monounsaturated	0.037 g
		Fatty acids, total polyunsaturated	0.087 g

Table 129 Respiration rate of loofah fruit (source: adapted from Zong *et al.* 1993)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	14
5	27
10	36
15	63
20	79

and indicated that stage 7 is the optimum harvest maturity. Sucrose content decreased from stage 5 to stage 8; fructose was the dominant sugar at maturity stage 8. Malic acid was the dominant organic acid; citric, fumaric and succinic acids were the minor ones. Malic acid content decreased through fruit maturation, while citric acid content remained nearly constant. Phenolic compounds and the ratio of ortho-diphenol to total phenolics increased during fruit maturation. β-Carotene was the dominant carotenoid at stage 2; cryptoxanthin became predominant at stage 7.

Prestorage treatment

Cai *et al.* (2011) found that methyl jasmonate enhanced activities of ascorbate peroxidase, glutathione peroxidase and glutathione-S-transferase,

Table 130 The composition of loquat fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.73 g	Total ascorbic acid	1.0 mg
Energy	47 kcal	Thiamine	0.019 mg
Protein	0.43 g	Riboflavin	0.024 mg
Total lipid (fat)	0.20 g	Niacin	0.180 mg
Carbohydrate, by difference	12.14 g	Vitamin B-6	0.100 mg
Total dietary fibre	1.7 g	Folate	14 µg DFE
Calcium	16 mg	Vitamin B-12	0.00 µg
Iron	0.28 mg	Vitamin A	76 µg RAE
Magnesium	13 mg	Vitamin A	1528 IU
Phosphorus	27 mg	Fatty acids, total saturated	0.040 g
Potassium	266 mg	Fatty acids, total monounsaturated	0.008 g
Sodium	1 mg	Fatty acids, total polyunsaturated	0.091 g
Zinc	0.05 mg		

and they suggested that methyl jasmonate can regulate the ascorbate and glutathione metabolism and has important roles in alleviating oxidative damage and enhancing chilling tolerance in loquat fruit.

Precooling

Shinbori and Nakai (1991) recommended precooling to less than 5 °C within 20 h of harvesting.

Postharvest physiology

Hamauzu *et al.* (1997) found that the respiration rate decreased during maturation and Ding *et al.* (1998) confirmed that the cultivar Mogi was non-climacteric. They also found that the rate of respiration at 20 °C was 34.4 mg CO₂ kg⁻¹ h⁻¹ on the first day of storage. After 4 days of storage their respiration rates were 80.0 at 20 °C, 30.6 at 10 °C, 12.4 at 5 °C and 11.2 mg CO₂ kg⁻¹ h⁻¹ at 1 °C. Fruits are not particularly sensitive to ethylene exposure postharvest and they produce relatively low amounts of ethylene, but production increased simultaneously with the decrease of green colour and the appearance of reddish colour.

Storage

Maojun *et al.* (2012) suggested that cold induced endogenous nitric oxide generation in loquat fruit

during storage at 1 °C, and 95% r.h. played a critical role in alleviating chilling injury symptoms by affecting the antioxidative defence systems in the fruit. Cai *et al.* (2011) reported that chilling injury symptoms were internal browning and the application of methyl jasmonate to fruit inhibited the incidence of chilling injury. At room temperature of 20 °C and 60% r.h. Mercantilia (1989) indicated that the fruit could be kept for 3–5 days, while Ding *et al.* (1998) found that at 20 °C they could be kept for up to 10 days. Refrigerated storage recommendations include:

- 0 °C and 90% r.h. for 2–3 weeks (Mercantilia 1989);
- 0 °C and 90% r.h. for up to 3 weeks (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 2–3 weeks (Snowdon 1990);
- 0 °C and 90% r.h. for 14–21 days (SeaLand 1991);
- 1 °C or 5 °C for up to 30 days (Ding *et al.* 1998);
- 10 °C for up to 15 days (Ding *et al.* 1998).

Modified atmosphere packaging

Storage in perforated PE film bags (0.15% perforation) was successfully used for the cultivar Mogi when stored at 1 or 5 °C in that besides reducing weight loss it decreased the rate of loss of organic acids (Ding *et al.* 1998).

Diseases

Liu *et al.* (2010) reported that *Colletotrichum acutatum* caused anthracnose in loquat fruit. They found that postharvest exposure of fruit to hot air at 38 °C for 36 h combined with the application of *Pichia guilliermondii* significantly reduced disease, infection incidence and lesion diameter by *C. acutatum* in artificially inoculated fruit thus reducing anthracnose rot.

Lovi lovi

Flacourtiaceae, Salicaceae

Flacourtia inermis Roxburgh, other common names include thornless rukam, governor's plum, lobi-lobi and tomi-tomi. *F. inermis* is only known in a cultivated or semi-cultivated state, widespread from India through Malaysia, Indonesia and Sri Lanka to New

Britain both for its fruit and decorative foliage. It is cultivated as a fruit tree up to 1300 m altitude, also on sandy soils.

It is a tree that can reach up to 15 m tall; with the trunk diameter is up to 35 cm. It produces edible fruit, which are subglobose, dark red when mature and containing many small seeds. The fruit is a globose berry, 2–2.5 cm in diameter, pink to red, sourish to sweet, sometimes pungent and many seeded. It is usually very astringent and must be cooked before eating, but there are low astringent sweet varieties. In Java, the tree flowers in January or February and fruit is ready for harvest after 4–5 months.

Lucuma

Sapotaceae

Lucuma bifera Mol., *L. obovata*, HBK, *Pouteria lucuma* (Ruiz and Pav.) O. Kuntze. Other common names include Lucumo, Lucmo, Lucma, Mamon and Rucma. It is a native of Peru and was an important part of the diet of ancient Peruvians where it was found in archaeological remains (Purseglove 1975). It grows wild and is also cultivated in southern Mexico, Central America, the West Indies, the Bahamas and, to a limited extent, in southern Florida (Morton 1987). It is an evergreen tree up to 10 m high. The fruit is round or ovate with a green skin and yellow flesh. It has a mealy texture and is some 7 cm long (Lizana 1980). The fruit is a climacteric with a high respiration rate (Lizana *et al.* 1986). It had a water content of 64–72% and high amounts of riboflavin and niacin (Lopez 1984). Yahia and Guttierrez-Orozco (2011) reported the composition of the fruit in Table 131. Harvest maturity is commonly based on the change of peel colour from green to yellow, but there is variability ranging from green to yellowish green for fully ripe fruit (Lizana 1980). Pulp colour and TSS can be used as a supplementary measure but the pulp is dense and dry, and the pulp has to be diluted with water, which might lead to the TSS appearing lower (Lizana *et al.* 1986). They also classified them into five classes for harvest maturity determination (Table 132).

Yahia and Guttierrez-Orozco (2011) reported that it was a climacteric fruit. Lizana (1980) reported that fruit ripened on the tree usually become soft, dry and very fragile, while Yahia and Guttierrez-Orozco

Table 131 The composition of lucuma fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	62 g	Vitamin C	5.4 mg
Energy	143.8 kcal	Thiamine	0.01 mg
Protein	2.3 g	Riboflavin	0.14 mg
Fat	0.2 g	Niacin	1.96 mg
Carbohydrate	33.2 g	Magnesium	
Calcium	16 mg	Phosphorus	26 mg
Iron	0.4 mg		

Table 132 Classification of lucuma fruit for harvest maturity (source: adapted from Lizana 1980)

Class	Peel colour	Pulp colour
1	Light yellow	Light yellow
2	Light green	Creamy yellow
3	Yellow green	Yellow
4	Green yellow	Dark yellow
5	Green yellow	Orange yellow

(2011) reported that although mature fruit fall from the tree they still need to ripen for several days before they can be consumed. Storage for more than 7 days at 7 °C affected ripening and quality negatively. They were reported to have been successfully stored at 13 or 18 °C and high humidity for up to 14 days with MA packaging contributing positively to maintenance of their quality (Yahia and Guttierrez-Orozco 2011).

Malay apple

Myrtaceae

Syzygium malaccense, Malay apple, *S. aqueum*, rose water apple, *S. aimini*, Java plum, *S. jambos*, rose apple. Basanta and Sankat (1995) and Sankat *et al.* (2000) referred *S. malaccense* as pomeac, and Le *et al.* (1998) referred Malay apple as *S. malaccense*, while Purseglove (1968) indicated that *S. malaccensis* (note the difference in spelling of the species name) is synonymous with *Eugenia malaccensis*. Also pomeac (*E. jambos*) has similar fruit characteristics and it seems more likely that its common name would be jambos. They originated in Malaysia and can be seen commonly on markets, especially in Southeast Asia. It is now grown throughout the tropical world often as a garden tree. The fruit is a berry with a



Figure 104 Rose apples on sale in Thailand. See colour plate section.

persistent calyx and is borne directly of the main trunk or the branches of the tree. They are pear shaped and bright red, pinkish or purple in colour with a thin skin and crisp white flesh, with a distinct rose scent (Figure 104). There is a central cavity containing a single round seed. The fruit can be up to 10 cm long but are usually considerably smaller. Its respiratory pattern led to it being classified as an indeterminate fruit by Biale and Barcus (1970).

Harvesting

Harvesting is by hand. Maturity can be judged on colour changes in the skin, and also the fruit becomes more rounded as it develops.

Storage

Fruits could be kept for 4–6 days under Trinidad ambient conditions of about 28 °C after which they deteriorate rapidly with increased fading of the fruit's bright, strikingly red skin colour (Sankat *et al.* 2000). Fruits stored at 10 or 15 °C and 95% r.h. were shrivelled and showed decay and skin colour loss after 10–15 days, but fruits stored at 5 °C had acceptable colour, firmness, taste and aroma, even after 20 days, although there were some signs of shrivelling (Basanta and Sankat 1995). In storage at 5 °C for 30 days those stored in the light had more fading of the red skin colour than those stored in the dark (Sankat *et al.* 2000).

Controlled atmosphere storage

Sankat *et al.* (2000) stored fruits at 5 °C for up to 30 days in 5% CO₂ with 2% O₂, 5% CO₂ with 4% O₂, 5% CO₂ with 6% O₂, 5% CO₂ with 8% O₂, 5% CO₂ with 1% O₂, 8% CO₂ with 1% O₂, 11% CO₂ with 1% O₂ or 14% CO₂ with 1% O₂. The optimum storage conditions were found to be 11% CO₂ with 1% O₂ and 14% CO₂ with 1% O₂ where fruits maintained their flavour and appearance for 25 days.

Modified atmosphere packaging

Waxing reduced shrivelling at 5 °C, but not as effectively as packing in polyethylene bags, which also preserved fruit colour and firmness (Basanta and Sankat 1995).

Transport

Wardlaw (1937) mentioned that a shipment of fruit had been made from Java to Holland, but was said to have no commercial value on arrival. There was no mention of the shipping conditions.

Mamey

Guttiferae

Mammea americana L., *Pouteria sapota* (Jacq.) H.E. Moore & Stearn, also known as Mamey Apple, Mammy Apple and Zapote. It is a native of South America and the West Indies. Mamey sapote is a large evergreen ornamental tree that can reach a height of 15–45 m at maturity. The edible portion is the fruit that are up to 20 cm in diameter and have a rough brown skin, often with a beaked tip. The pulp is orange in colour and apricot in flavour and contains up to four large seeds. The chemical content was given by USDA (2012) in Table 133. The fruit is widely eaten raw, but Morris *et al.* (1952) found that all parts of the tree contained a principle that was toxic to guinea pigs. When cut a bitter yellow resin is exuded from all parts of the tree except the fruit pulp. This yellow resin, which is also extracted from the seeds, can be used as an insecticide.

Harvesting

It is considered to be ripe when the flesh is pink which can be judged by carefully lifting a piece of the thin skin with the fingernail.

Table 133 The composition of mamey fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.20 g	Zinc	0.10 mg
Energy	51 kcal	Total ascorbic acid	14.0 mg
Protein	0.50 g	Thiamine	0.020 mg
Total lipid (fat)	0.50 g	Riboflavin	0.040 mg
Carbohydrate, by difference	12.50 g	Niacin	0.400 mg
Total dietary fibre	3.0 g	Vitamin B-6	0.100 mg
Calcium	11 mg	Folate	14 µg DFE
Iron	0.70 mg	Vitamin B-12	0.00 µg
Magnesium	16 mg	Vitamin A	12 µg RAE
Phosphorus	11 mg	Vitamin A	230 IU
Potassium	47 mg	Fatty acids, total saturated	0.136 g
Sodium	15 mg	Fatty acids, total monounsaturated	0.205 g
		Fatty acids, total polyunsaturated	0.079 g

Postharvest physiology

Akamine and Goo (1978) found that Mamey apple was a climacteric fruit. They reported that the ethylene production of fruit at 27 °C was up to 400 µL kg⁻¹ h⁻¹, among the highest of all fruits, and their respiration rate at 27 °C was 28–40 mg (14–20 µL) CO₂ kg⁻¹ h⁻¹.

Storage

SeaLand (1991) recommended 12.8 °C and 90–95% r.h. for 14–42 days. Manzano-Mendez and Dris (2001) showed that storage of Mamey Amarillo fruits at 15 ± 2 °C in 1% CO₂ + 5.6% O₂ + 89.3% N₂ for 2 weeks retarded their maturation. They suffer from chilling injury, and the symptoms were described by Yahia (2002) as failure to ripen, accelerated softening, development of brown spots in pulp, and development of off-flavours and aromas.

Mandarin

Rutaceae

Citrus reticulata Blanco, *C. unshiu* (Swingle) Mar-cow. The fruit is a berry or hesperidium, which is non-climacteric. The term *Mandarin* is used throughout Japan, China, Italy and Spain, and they are referred to as *soft citrus* in South Africa (Davies and Albrigo 1994). Inaba *et al.* (1989) found that there

was increased respiration in response to ethylene at 100 µL L⁻¹ for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures.

Harvesting and handling

The fruit changes in colour from green to reddish orange as they mature on the tree, and the skin becomes smoother. The juice content also increases. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit, it is possible to specify its maturity. In the United States the minimum value is 33%. The ratio between soluble solids and acidity can also be used; it should be within the range of 7:1 and 9:1. Tariq (1999) found that scuffing of the peel was the worst damage, and resulted in the peel turning brown and *Penicillium* spp. growing on the damaged area. Cuts and bruises were found to be less injurious to fruits than scuffing.

1-MCP

Mandarins can be marketed with some leaves attached to the fruit to show their freshness. Qing Li *et al.* (2012) treated freshly harvested fruit of the cultivar Shatangju with 5 µL L⁻¹ 1-MCP for 16 h then stored them for 20 days at 20 °C. Those treated with 1-MCP had inhibited leaf abscission, chlorophyll degradation and senescence compared to those that had not been treated, and the treatment did not influence fruit quality.

Curing

Placing the damaged fruits in sealed polyethylene film bags and exposing them to temperatures in the range of 25–35 °C for between 3 and 48 h completely eliminated the browning and fungal growth of damaged fruits. The lower the temperature is, the longer will be the exposure time required for the curing process. Curing could be achieved without film packaging at the same temperature if the surrounding atmosphere was maintained at the same temperature range in 95–98% r.h. (Tariq 1999).

Degreening

Optimum temperatures range between 25 and 29 °C and humidity as high as possible, generally between

90 and 95% r.h. with ethylene at between 1 and 10 $\mu\text{L L}^{-1}$ for 24–72 h. The actual choice of conditions will vary between different situations, particularly whether they have been grown in the tropics or subtropics. The cultivar and the stage of maturity at harvest should also be taken into account.

Storage

Tietel *et al.* (2012) reported that the recommended minimum safe temperature for mandarin storage was 5–8 °C, but because of continuing reductions in permitted chemical residues and increasing concern regarding decay development they are often shipped at 3–4 °C. They evaluated changes in flavour and quality of the chilling-tolerant cultivar Or and the chilling-sensitive cultivar Odem after 4 weeks of storage at 2, 5 or 8 °C followed by 3 days at 20 °C. They reported that low storage temperatures resulted in loss of orange peel colour in both cultivar, which became paler and yellowish and the flavour of Or was not affected by different storage temperatures, whereas Odem showed severe flavour loss in low storage temperatures. Refrigerated storage recommendations include:

- 5.6–7.2 and 85–90% r.h. for 8 weeks with 13% loss (Coorg main crop) or 6 weeks with 15.8% loss for Coorg in the rainy-season crop (Pantastico 1975);
- 0–3 °C and 85–90% r.h. for 8–10 weeks (Mercantilia 1989);
- 4–8 °C and 90% r.h. for 3–8 weeks (Snowdon 1990);
- 7.2 °C and 85–90% r.h. for 14–28 days (SeaLand 1991);
- 0–4 °C for 2 months or more (Davies and Albrigo 1994);
- 4 or 8 °C and 90% r.h. for 3 months for Malvasio Mandarins grown in Sardinia (Agabbio *et al.* 1999).

Diseases

Geotrichum sp. is a soil-borne fungus that can infect fruit and cause the disease called sour rot. Control of the disease is usually associated with field sanitation and avoiding injury to fruit (Snowdon 1990). However, Feng *et al.* (2012) carried out experiments to investigate the antifungal activities of postharvest treatment with polyhexamethylene biguanide and polyhexamethylene guanide against sour rot

(*G. citri-aurantii*) both *in vitro* and *in vivo* on the cultivar Shatang. They both significantly reduced the growth of the fungus *in vitro* and also reduced sour rot development on artificially inoculated fruit. Hao *et al.* (2010) found that tea saponin alone or in combination with a low rate of prochloraz or imazalil significantly reduced postharvest decay in the cultivar Shatang without impairing any of the fruit quality parameters. They found that the best ratio of tea saponin to a low rate of prochloraz or imazalil to control *Penicillium italicum*, *P. digitatum* and *G. candidum* was 8:2.

Pantastico (1975) mentioned puffiness where the peel becomes soft and very loose and may crack, which appears to be associated with water loss from the segments.

Mango

Anacardiaceae

Mangifera indica L. It is thought to be of Indo-Burma origin and grows wild in the forests of India and has spread throughout the sub-continent where it has been cultivated for 4000 years or more. It was probably taken to east Asian countries by Indians in the 5th and 4th centuries BCE and to east Africa in the 10th century CE (Purseglove 1975). It is grown in the tropics from sea level up to about 1200 m. Total world production of mangoes, mangosteens and guavas in 2010 was estimated by FAO (2013) as 37,124,742 tonnes.

They are tall evergreen trees. The fruit is a fleshy drupe with a yellow or green often with a red or yellow blush. They vary in weight depending on variety or cultivar form less than 100 g to 1 kg and can be round, oval or kidney shaped. Some varieties have a turpentine like smell and taste. The fruit are high in carotenoids, anthocyanins and chlorophyll, which change during ripening (Figure 105). This effect was similar for carotenoids on the three cultivars tested (Figure 106). They will freeze at about –1.3 to –1.1 °C (Wright 1942).

Chemical content

The chemical content was given by USDA (2012) in Tables 134 and 135 by Morton (1987). Some varieties have a distinct turpentine aroma and flavour; there

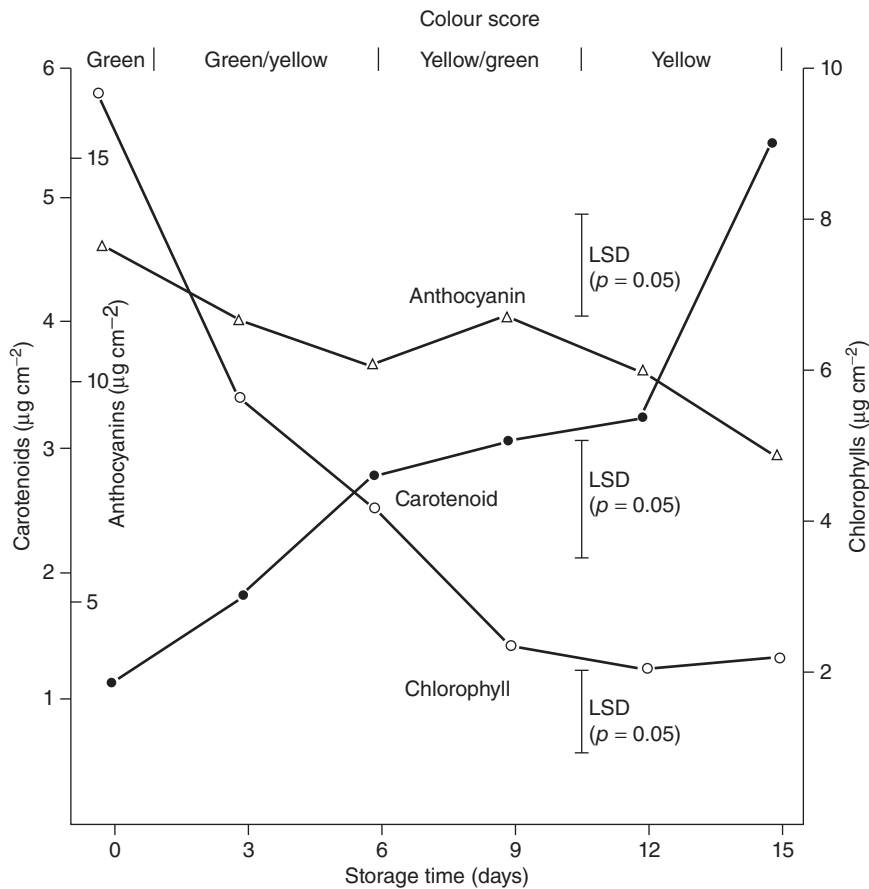


Figure 105 Changes in mango pigments during ripening. (Source: Medlicott *et al.* 1986a. Reproduced with permission of John Wiley & Sons Ltd.)

is even a variety called turpentine. Turpentine is oleoresin whose two principal components are an essential oil and a resin that is called rosin. It is better known for being exuded from the sapwood of some conifers from which it is extracted for use in paint and other products.

Starch

As in other climacteric fruit, starch content usually increases in mangoes during maturation and is predominantly in the pulp. It is hydrolysed into sugars during ripening (Medlicott *et al.* 1986b). The starch concentration in the pulp of the cultivar Mahajanaka was 46.31% dry weight 105 days after fruit set and 55.17% dry weight 140 days after fruit set when they were considered to be fully mature (Mattoo *et al.* 1975). At the fully mature stage starch

concentration on a dry weight basis was 23.38% for Willard, 42.65% for Malgova, 49.64% for Karutha Colomban, 55.17% for Mahajanaka and 29.88% for Tommy Atkins (Vergara-Valencia *et al.* 2007). Lima *et al.* (2001) reported that during ripening there was an increase in amylase activity and sugar content while there was a concomitant decrease in starch content during the climacteric rise in respiration rate.

Sugars

Sucrose, glucose and fructose are the major sugars in ripe mango fruit, with sucrose contributing more than 80% of the total sugars (Figure 64) (Hymavathi and Khader 2005). Total sugar concentration in ripe Haden was about 50–120 mg g^{-1} fresh weight, with sucrose contributes about 74.1% of the total sugars followed by 20.6% for fructose

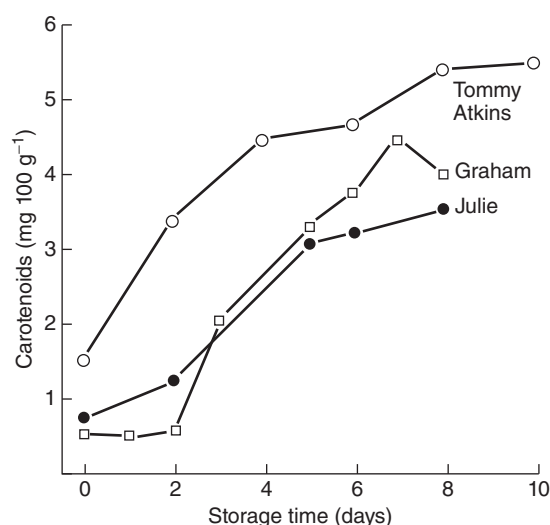


Figure 106 Changes in mangoes during ripening. (Source: Medlicott and Thompson 1985. Reproduced with permission of John Wiley & Sons Ltd.)

and 5.3% for glucose (Rathore *et al.* 2007). Srivastava (1967) reported mean levels of seven Indian varieties as 2.36% for glucose, 3.71% for fructose and 9.83 for sucrose with the mean TSS content as 18.9%. USDA (2012) reported total sugars as 13.66 g 100⁻¹ (Table 134). Ripe Carabao was reported to have comparatively higher concentration of total sugar while very low sugar content was reported in the cultivar Golek. Sugars composed about 91% of the TSS from the mesocarp of the ripe cultivar Ngowe (Brinson *et al.* 1988). Fructose was the predominant reducing sugar found in most of the cultivars and exhibited a fivefold increase during ripening, however, sucrose increased in the later stages of ripening. This was consistent with the increased activity of gluconeogenic enzyme in the ripe fruit of several cultivars (Selvaraj *et al.* 1989, Fuchs *et al.* 1980). Total and non-reducing sugars of the ripe fruit of the cultivar Delta R2E2 were higher in fruits stored at room temperature than those stored in CA while reducing sugars were higher in fruits that ripened at CA storage (Lalel *et al.* 2005). Kensington Pride stored at room temperature contained higher total sugar content of 15.90% dry weight compared to polyamine-treated fruits where the total sugars were 13–15.61% dry weight (Malik and Singh 2006).

Table 134 The composition of mango fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	83.46 g	Thiamine	0.028 mg
Energy	60 kcal	Riboflavin	0.038 mg
Protein	0.82 g	Niacin	0.669 mg
Total lipid (fat)	0.38 g	Vitamin B-6	0.119 mg
Carbohydrate, by difference	14.98 g	Folate	43 µg DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Total sugars	13.66 g	Vitamin A	54 µg RAE
Calcium	11 mg	Vitamin A	1082 IU
Iron	0.16 mg	Vitamin E	0.90 mg
		(α-tocopherol)	
Magnesium	10 mg	Vitamin D	0.0 µg
		(D2 + D3)	
Phosphorus	14 mg	Vitamin D	0 IU
Potassium	168 mg	Vitamin K (phylloquinone)	4.2 µg
Sodium	1 mg	Fatty acids, total saturated	0.092 g
Zinc	0.09 mg	Fatty acids, total monounsaturated	0.140 g
Total ascorbic acid	36.4 mg	Fatty acids, total polyunsaturated	0.071 g

Table 135 The minimum and maximum compositions of ripe mango flesh derived from various analyses made in Cuba, Central America, Africa and India for 100 g⁻¹ fresh weight (source: Morton 1987)

Calories	62.1–63.7	Iron	0.20–0.63 mg
Moisture	78.9–82.8 g	Vitamin A	0.135–1.872 mg
		(carotene)	
Protein	0.36–0.40 g	Thiamine	0.020–0.073 mg
Fat	0.30–0.53 g	Riboflavin	0.025–0.068 mg
Carbohydrates	16.20–17.18 g	Niacin	0.025–0.707 mg
Fibre	0.85–1.06 g	Ascorbic acid	7.8–172.0 mg
Ash	0.34–0.52 g	Tryptophan	3–6 mg
Calcium	6.1–12.8 mg	Methionine	4 mg
Phosphorus	5.5–17.9 mg	Lysine	32–37 mg

Acids

Citric is the major acid in mango fruit and decreases during ripening while oxalic and tartaric showed irregular variations and ascorbic and malic acids increased slightly (Figure 64) (Modi and Reddy 1967, Medlicott and Thompson 1985). Shashirekha and Patwardhan (1976) reported that citric acid in the cultivar Badami decreased by about 10-fold during

ripening with a slight increase of malic acid. Both peel and pulp of mango fruit are good source ascorbic acid, but the concentration varied depending on cultivar, tissues, stage of maturity, ripening, storage, climatic conditions, cultural practices and preharvest and postharvest factors. Ascorbic acid concentration of pulp of some cultivars was Keitt, 0.33 mg g^{-1} ; Kent, 0.32 mg g^{-1} (Vinci *et al.* 1995) and Tommy Atkins, 0.26 mg g^{-1} (Mansour *et al.* 2006) with Langra and Haden having higher concentrations (Tovar *et al.* 2001). USDA (2012) gave the total ascorbic acid as 0.364 mg g^{-1} (Table 134) and Morton (1987) gave the range as $0.078\text{--}1.72 \text{ mg g}^{-1}$ (Table 135).

Pigments

The colour of unripe pulp turns from creamy white to yellow-orange during ripening in most cultivars while peel colour turns from green to yellow or red often with a red or orange blush depending on the cultivar. The colour change in the peel is mainly caused by the conversion of chlorophyll to the colourless chemical called phytol. Chlorophyll masks the other pigments but there is also synthesis of anthocyanins and carotenoids during ripening. Carotenoids are the main pigments in the pulp of ripe mango fruit particularly β -carotene that contributes 48–80% of total carotenoid in most mango cultivars (Cano and De Ancos 1994, Chen *et al.* 2004). John *et al.* (1970) reported that phytofluene was the main carotenoid in ripe mangoes, whereas β -carotene was the major carotenoid in unripe mangoes. Beside β -carotene, carotenoids such as violaxanthin, mutaloxanthin and luteoxanthin have also been found in different Brazilian mango cultivars (Godoy and Rodriguez-Amaya 1989). In addition to all-trans- β -carotene, Keitt contains that all-trans-violaxanthin and 9-cisviolaxanthin are also major carotenoids in mangoes. Carotenoid composition is affected by growing conditions and climate, stage of maturity, cultivar and storage condition (Mercadante *et al.* 1997). The β -carotene content was $8 \mu\text{g g}^{-1}$ fresh weight in the cultivar Malgoa compared to Alphonso with $130 \mu\text{g g}^{-1}$ fresh weight (Hymavathi and Khader 2005) or $110 \mu\text{g g}^{-1}$ fresh weight also for Alphonso (Padmini and Prabha 1997). Ataulfo was given as $12 \mu\text{g g}^{-1}$ fresh weight

for total carotenoids and $5 \mu\text{g g}^{-1}$ fresh weight for β -carotene (Corral-Aguayo *et al.* 2008).

Aroma volatiles

Cultivars differ widely on the type and concentration of volatile compounds. Their nature and concentration also varies between peel and pulp and, of course, during ripening. Engel and Tressl (1983) and MacLeod and Pieris (1984) reported that the characteristic flavour of mangoes could not be attributed to any specific component but *cis*-ocimene and β -myrcene may be responsible for the green aroma of unripe fruit while dimethylstyrene has a ripe mango-like character. Pino and Mesa (2006) concluded that ethyl-2-methylpropanoate, ethyl butanoate, E,Z-2,6-nonadienal, E-2-nonenal, methyl benzoate, E- β -ionone, decanal and 2,5-dimethyl-4-methoxy-3,2H-furanone were the important components responsible for the aroma of mangoes. They found that other volatile components did not make any significant impact on mango aroma. Selvaraj *et al.* (1989) identified Z-ocimene as the principal volatile constituent of Alphonso and other Indian mango cultivars. However, MacLeod and Pieris (1984) demonstrated that Z-3-hexenyl esters were responsible for the fresh, green fruity flavour of Alphonso while C9-lipid oxidation product, E-2-nonenal gave the melon-like aroma and flavour of the cultivar Baladi. Several volatile components including ethanol, acetic acid, amyl acetate and phenyl ethanol acetate have been identified in extracts of over-ripe mango fruits (Zhu *et al.* 2003). Lalel *et al.* (2003) identified 61 aroma volatile compounds emitted during ripening of the cultivar Kensington Pride. Hydrocarbons accounted for about 59% of the total identified compounds, followed by esters 20%. Alpha-terpinolene was the major aroma compound during the first 7 days of ripening and later ethyl octanoate became the major aroma compound. Except for car-3-ene, the concentration of major monoterpenes increased for the first 3 or 4 days and decreased afterwards. Most of the major sesquiterpenes were intensively synthesized in the early part of the ripening process. The production of three major esters increased sharply during fruit ripening. It appeared that production of

terpenes was parallel with production of ethylene, while production of esters appeared to be associated with production of fatty acids.

Prestorage treatments

Hofman *et al.* (2001) showed that 1-MCP at $25 \mu\text{L}^{-1}$ for 14 h at 20°C increased the time to ripening by 5.1 days (37%) in the cultivar Kensington Pride but treatment at least doubled the severity of stem rots compared to non-treated fruit. However, they concluded that 1-MCP treatment has the potential to reduce the risk of premature fruit ripening because of accidental exposure to ethylene. The cultivar Nam Dok Mai was treated with 500 ppb 1-MCP and then stored at 13°C in 3% O_2 + 5% CO_2 by Kramchote *et al.* (2008). They reported that storage in the CA was the most effective way to delay fruit yellowing, while 1-MCP was more effective in maintaining firmness and suppressing ethylene production. The production of aroma volatile compounds emitted after 28 days of storage showed the accumulation of high levels of ethanol for fruits in 3% O_2 + 5% CO_2 , while 1-MCP treatment mainly suppressed volatile emission. Wang *et al.* (2007) harvested the cultivar Tainong at the green-mature stage and treated them with $1 \mu\text{L}^{-1}$ 1-MCP for 24 h and stored them at 20°C for up to 16 days. 1-MCP maintained fruit firmness and ascorbic acid but inhibited the activities of antioxidant enzymes including catalase, superoxide dismutase and ascorbate peroxidase. González-Aguilar *et al.* (2001) also found that UV-C irradiation for 10 min of ripe Tommy Atkins mangoes was effective in suppressing decay and maintaining firmness during storage.

Harvesting

Harvest maturity is judged on skin colour, firmness of the flesh, size, shape and aroma. The cultivars Tommy Atkins and Kent were harvested at 15–17 lbs pulp pressure by Lizana and Ochagavia (1997). Specific gravity of the fruits showed a decreasing trend up to 45 days after fruit set and a linear increase up to maturity of fruits in all the cultivars, whereas TA increased after fruit set and then slowly decreased towards maturity. Ascorbic acid and moisture content of the fruits decreased after fruit set to maturity and maximum values were observed in the cultivar

Langra. However, TSS and total sugar content of the fruits showed an increase after fruit set up to maturity and they were highest in Langra and Sunderja.

Mangoes also change shape during maturation on the tree. For some cultivars this change could be correlated in a systematic way with maturity. As the mango fruit matures the relationship between the shoulders of the fruit and the point at which the fruit-stalk is attached to the fruit may change. On very immature mango fruits the shoulders slope away from the fruit stalk, on more mature fruit the shoulders become level with the point on attachment and on even more mature fruit the shoulders may be raised above the point of attachment. Wardlaw and Leonard (1936) gave the following definitions:

1. Fruits almost fully-grown, green in colour and with shoulders level with the stem insertion.
2. Shoulders raised above the stem insertion because of further fruit growth and the skin a lighter green in colour.
3. No further growth but fruits on the point of becoming soft, and colour present in the skin.

Using this method of determining mango fruit maturity Thompson (1971a) showed that the percentage of fruit still unripe after storage at 7°C for 28 days was 68, 57 and 41%, respectively, for A, B and C maturity stages.

The time after flowering can also be used to determine harvest maturity. In India Alphonso exhibited a sigmoid pattern of growth and took 16 weeks from fruit set to attain harvest maturity (Rao *et al.* 1995). Rajput *et al.* (1999) showed that the fruit growth of the cultivars Langra, Sunderja, Mallika and Amrapali also followed a sigmoid pattern and in general it was rapid between 30 and 90 days after fruit set. Kienzle *et al.* (2012) evaluated harvesting 83–107 days after full bloom for the cultivar Chok Anan. They found that fruit were harvested 89 days after full bloom and stored at 14°C and 50–60% r.h. with ethylene absorption took 17–19 days to reach eating ripeness. Fruits of Karuthacolomban, Velleicolomban and Willard, grown in Sri Lanka, were harvested at 10, 11, 12 and 13 weeks after flowering. Peel colour development could be used to determine harvest maturity in Willard. Changes of dark green to light green with maturity could not be considered as a reliable index for the other two cultivars. Rising of shoulders with maturity is a

better indicator of maturity than peel colour development, and it could be used as a reliable index to harvest all three cultivars. Though mature fruits of Willard and Velleicolomban passed the float test, Karuthacolomban did not respond consistently. The mean value of TSS recorded from Karuthacolomban and Velleicolomban harvested 13 weeks after flowering was 18°Brix, while TA was 0.3%. TSS and TA of Willard were similar to these values in the twelfth week after flowering. The fruits harvested before the optimum stage of maturity contained significantly lower TSS, higher TA and poorer sensory properties than mature fruits (Amarakoon *et al.* 1999).

As mentioned previously specific gravity is used to grade crops into different maturities postharvest. To do this the fruit is placed in a tank of water and if they float they will be less mature than those which sink. To give greater flexibility to the test and make it more precise, a salt or sugar solution can be used in place of water in the tank. This changes the density of the liquid resulting in fruits that would have sunk in water, floating in the salt or sugar solution. Lizada (1993) showed that a 1% sodium chloride solution was suitable for grading Carabao mangoes in the Philippines.

Acoustic and vibration tests equipment puts vibration energy into a fruit and measures its response to this input. Good correlations have been found using the second resonant frequency to determine mango maturity (Darko 1984, Punchoo 1988). Near-infrared reflectance has been studied in relation to measuring the internal qualities of fruit with good correlation with sugar content (Kouno *et al.* 1993a, 1993b).

Mangoes are harvested by hand and the trend to grow them on grafted trees or use other methods to control their size has facilitated harvesting. Some varieties, e.g. Julie, are dwarf trees and for commercial production selected cultivars are grafted onto dwarfing rootstocks, e.g. Sabre from South Africa. Grafting onto dwarfing rootstocks can result in trees with spreading branches, but the shape of the canopy also depends on the space available. Selection of polyembryonic dwarfing varieties, e.g. Olour, Vellai Colomban and Pahutan in India, Manzo de Ica in Peru, Hilaza and Puerco in Colombia, Kitchener in the Sudan and Kaew in Thailand for rootstocks facilitates their propagation. The cold-hardy rootstock of

Gomera-1 is well adapted to the coastal Mediterranean climate and originally was selected in Cuba.

Where fruit are grown on large trees various ways have been developed to facilitate harvesting from the higher branches. Traditionally the harvester would carry a ladder and use that to reach the fruit or the harvester may climb the tree. This is very time consuming and various ways have been developed to speed up the operation. A long pole with a bag at the end together with some device for cutting or breaking the fruit stalk is commonly used (Figure 107). Picking platforms are available which enable the harvester to be towed around the orchard from tree to tree so the platform can be raised and lowered enabling the fruit to be picked (Figure 16). Martín-Salih and Ruhni (1993) described a prototype hand-held mango harvester. It consisted of an adaptation of the commonly used pole with a bag attached. The new design had a cutter bar attached at the end of the pole above the bag that was operated from a small electric motor powered by a 12-V battery. The way the fruit is actually removed from the tree can be important and clipping with secateurs is recommended.



Figure 107 Bag and cutter used for attaching to a long pole for harvesting mangoes in Colombia. See colour plate section.

Packhouse

Various graders are used in mango packhouses because of the need to size grade fruit in order to pack them to a standard weight. The standard weight is commonly 4.5 kg per box for export and the fruit are graded into different sizes and packed with the appropriate number per box. In Brazil a small weight grader was produced for mangoes. The fruit were fed into it by hand and an electric motor transported the fruit around on a belt, which allowed fruit of the different weights to be gently run off into different bins (Figure 108). The machines were constructed locally and had the advantage of being able to be operated by a hand crank if there was a cut in the electricity. Thompson (1996) described the types of corrugated fibreboard boxes cartons used for international transport of mangoes. They included open corrugated board box with fold-in stacking rims, slotted corrugated board box with built-in dividers, three-piece fibreboard box with wooden frame, bliss box and telescopic box. The boxes are normally delivered to the packhouse flat and assembled by simple folding. They are all delivered and assembled on site. Interlocking designs are preferred that do not require staples as these can damage the fruit if not properly assembled. It is better to use a cassava starch-based adhesive for boxes that need it e.g. full-telescopic or half-telescopic cartons. Cartons should be suitable for stacking in columns as well as interlocking patterns. Medlicott (2000) reported that various containers are used for packing mangoes depending on the market. For export they



Figure 108 Circular mango weight grader in use in a packhouse in Brazil. See colour plate section.

are commonly packed in single-layer one-piece or two-piece full-telescopic, self-locking fibreboard cartons with a bursting strength requirement of 250–275 pounds per square inch. Ventilation and handle holes provide adequate ventilation and ease of handling.

The Organisation de Coopération et de Développement Économiques, Paris published a brochure of standards for mangoes in 1993. Medlicott *et al.* (1987a) showed that Brazilian mangoes varied in quality for the same variety throughout the harvest season. The early-maturing fruit tended to have better quality and postharvest characteristics than those that matured later.

Chilling injury

Symptoms of chilling injury include greyish, scald-like discoloration on the skin followed by pitting and uneven ripening as well as poor flavour and colour development. Tolerance to chilling was shown to increase during ripening (Medlicott *et al.* 1990). Storage of the cultivars Tommy Atkins and Keith at 12 °C caused slight chilling injury symptoms on the fruit peel expressed as red spots around the lenticels (Pesis *et al.* 1999). González-Aguilar *et al.* (2000a, 2000b) found that exposure of Tommy Atkins to methyl jasmonate vapours (10–4 M) for 24 h at 25 °C reduced chilling injury during subsequent storage for 21 days at 7 °C and after 5 days of shelf life at 20 °C. Chidtragool *et al.* (2012) found that in the fruit of the cultivar Nam Dok Mai storage at 4 °C resulted in peel browning within 9 days, while no browning was found in the cultivar Choke Anan fruit stored at 4 °C for 30 days. During 6 days subsequent shelf life at 27–28 °C the peel browning in Nam Dok Mai increased if not yet maximal, whereas little browning was observed in Choke Anan fruit. The pulp of the fruit of both cultivars did not show browning during the 4 °C storage, but the pulp of cv. Nam Dok Mai showed some browning during shelf life if the fruit had been stored at 4 °C for more than 18 days. They also found a high correlation between peel browning and phenylalanine ammonia-lyase activity in the peel. The cultivar Kensington Pride was stored at 5 ± 1 °C for either 2 or 4 weeks by Zaharah and Singh (2012). Treatment with 10, 20 and 40 µl L⁻¹ nitric oxide before storage significantly alleviated chilling injury in fruit during subsequent ripening at 21 ± 1 °C and suppressed

Table 136 Respiration rate mango fruit (source: adapted from Karmarkar and Joshi 1941; Lam and Kosiyachinda 1987)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
4.5	10–22
10	23–46
15	45–90
20	75–151

ethylene production and respiration rate irrespective of the cold storage period.

Postharvest physiology

Fruit have moderate ethylene production of 1–2 $\mu\text{kg}^{-1} \text{h}^{-1}$ at 20 °C and are very susceptible to postharvest exposure. The fruit has a climacteric pattern of respiration rate (Biale and Barcus 1970) and Vega Pina *et al.* (2000) found that fruits of the cultivar Haden reached their climacteric peak after 6 days at 21 °C. Respiration rate was given in Table 136.

Storage

Storage at 6 °C for 10 days, 13 °C for the next 10 days and 6 °C for the last 10 days were recommended by Muñoz *et al.* (1998). Fruits stored continuously at 6 °C did not develop carotenoid pigments, while the maximum storage period at 13 °C was less than 20 days. General refrigerated storage recommendations include

- 12 °C and 85% r.h. for 2–3 weeks (Mercantilia 1989);
- 20 °C and 60% r.h. for 3–4 days (Mercantilia 1989);
- 13.3 °C and 85–90% r.h. for 14–25 days (SeaLand 1991);
- 10–14 °C and 85–90% r.h. with 2–5% O₂ and 5–10% CO₂ for 1–4 weeks (Burden 1997);
- 12 °C and 3–4% O₂ with 25% CO₂ for 3 weeks for mature-green Tommy Atkins, Haden, Keitt and Kent (Bender *et al.* 2000a).

Bender *et al.* (2000a) reported that tree ripe Tommy Atkins, Haden, Keitt and Kent fruits could be stored at lower temperatures as follows: 8 °C with 3–4% O₂ plus 25% CO₂ for 3 weeks at 8 or 5 °C with 5% O₂ plus 10% CO₂ for 3 weeks with no evidence of chilling injury.

However, storing tree-ripe mangoes in controlled atmosphere storage at 12 °C for even 2 weeks was not successful due to zero shelf life following storage (Bender *et al.* 2000b). Storage at O₂ levels of 1% resulted in the production of 'off flavours' and skin discoloration (Hatton and Reeder 1966). General controlled atmosphere storage recommendations were as follows:

- 12 °C with 5% CO₂ and 5% O₂ for 20 days (Hatton and Reeder 1966);
- 13 °C with 5% CO₂ and 5% O₂ (Pantastico 1975, SeaLand 1991);
- 10–15 °C with 5% CO₂ and 5% O₂ (Kader 1986);
- 10–15 °C with 5–10% CO₂ and 3–5% O₂ (Kader 1989, 1992).

Storage recommendations for some varieties were

Alphonso

- 5.6–7.2 °C and 85–90% r.h. (Mathur *et al.* 1953);
- 8–10 °C and 85–90% r.h. for up to 4 weeks (Anonymous 1967).

Alphonso from India

- 7–9 °C and 90% r.h. for 7 weeks (Snowdon 1990).

Alphonso from the United States

- 13 °C and 90% r.h. for 2–3 weeks (Snowdon 1990).

Amelie

- 11 °C with 5% O₂ and 5% CO₂ for 4 weeks (Medlicott and Jeger 1987).

Bangalore

- 7–9 °C and 85–90% r.h. for 4–7 weeks (Anonymous 1967);
- 5.5–7 °C and 90% r.h. for 7 weeks (Snowdon 1990).

Caraboa

- 7.2–10 °C and 85–90% r.h. for 17–24 days with 5.1% loss (Pantastico 1975);
- 8 °C with 10% CO₂ and 6% O₂ for 4–6 weeks (Bleinroth *et al.* 1977).

Ceylon

- 10 °C for 3 weeks (Wardlaw and Leonard 1936, Thompson 1971a).

Haden

- 12.8 °C and 85–90% r.h. for 2–3 weeks (Lutz and Hardenburg 1968);
- 8 °C with 10% CO₂ and 6% O₂ for 4 weeks (Bleinroth *et al.* 1977);
- 10–11 °C with under 2% O₂ and either 1 or 5% CO₂ for 6 weeks (Medlicott and Jeger 1987);
- 12–14 °C and 90% r.h. for 2 weeks (Snowdon 1990).

Irwin

- 10 °C and 85–90% r.h. for 3 weeks (Irwin) (Lutz and Hardenburg 1968).

Jasmin

- 8 °C with 10% CO₂ and 6% O₂ for 6 weeks (Bleinroth *et al.* 1977).

Julie

- 10 °C for 3 weeks (Wardlaw and Leonard 1936, Thompson 1971a);
- 11 °C with 5% O₂ and 5% CO₂ for 4 weeks (Medlicott and Jeger 1987);
- 11–12 °C and 90% r.h. for 2 weeks (Snowdon 1990).

Keitt

- 12.8 °C and 85–90% r.h. for 2–3 weeks (Lutz and Hardenburg 1968);
- 12–14 °C and 90% r.h. for 2 weeks (Snowdon 1990).

Kent

- 12 °C with 10% CO₂ and 5% O₂ at 12 °C from 21 days in air to 29 days (Lizana and Ochagavia 1997).

Khuddus

- 7–9 °C and 85–90% r.h. for 4–7 weeks (Anonymous 1967).

Neelum

- 5.6–7.2 °C and 85–90% r.h. (Mathur *et al.* 1953).
- 5.5–9 °C and 90% r.h. for 5–6 weeks (Snowdon 1990).

Pedda

- 7–9 °C and 85–90% r.h. for 4–7 weeks (Anonymous 1967).

Pico

- 7.2–10 °C and 85–90% r.h. for 17 days with 6.2% loss (Pantastico 1975).

Raspuri

- 5.6–7.2 °C and 85–90% r.h. (Mathur *et al.* 1953);
- 7–9 °C and 85–90% r.h. for 4–7 weeks (Anonymous 1967);
- 8.3 °C and 85–90% r.h. for 4 weeks with 6.8% loss (Pantastico 1975);
- 5.5–9 °C and 90% r.h. for 5–6 weeks (Snowdon 1990).

Safeda

- 7–9 °C and 85–90% r.h. for 4–7 weeks (Anonymous 1967);
- 5.5–7 °C and 90% r.h. for 7 weeks (Snowdon 1990).

San Quirino

- 8 °C with 10% CO₂ and 6% O₂ for 6 weeks (Bleinroth *et al.* 1977).

Seedling types

- 5.6–7.2 °C and 85–90% r.h. (Mathur *et al.* 1953).

Tommy Atkins

- 12 °C with 5% CO₂ and 5% O₂ for 31 days (Lizana and Ochagavia 1997).

Zill

- 10 °C and 85–90% r.h. for 3 weeks (Lutz and Hardenburg 1968);
- 10 °C and 90% r.h. for 3 weeks (Snowdon 1990).

Modified atmosphere packaging

Fruits stored in polyethylene film bags at 21 °C had almost twice the storage life of fruits stored without wraps (Thompson 1971b). After 3 weeks of storage of Tommy Atkins and Keith at 12 °C plus 1 week at 20 °C in either modified atmospheres or controlled atmospheres (5% CO₂ and 15% O₂) had less red spotting on the peel compared to controls. The most effective reduction in chilling injury symptoms, expressed as red spots, was found in fruits that were packed in the Xtend film. Another advantage of the Xtend film was a reduction in the level of fruit sap inside the package as compared to polyethylene film. This was attributed to the lower humidity in the Xtend film, less than

95%, compared to 99% r.h., which was recorded in the polyethylene film (Pesis *et al.* 1999).

Ripening

A simple method of ripening was to place the fruit in baskets lined with banana leaves with calcium carbide, which gave fruit of uniform colour within 2–3 days at Malaysian ambient conditions, but with inferior flavour to fruits ripened without calcium carbide (Berwick 1940). Calcium carbide was also used to ripen fruit in South Africa, where they were placed in a room at 21.1–26.7 °C and 85–90% r.h. and calcium carbide was introduced at 1 ounce per 72 feet³ (28.35 g per 2.04 m³) for 1–2 days with ventilation every 4 h (Marloth 1947). A similar practice was used commercially on mangoes for airfreight export from Brazil where the harvested fruit were kept under gas-tight tarpaulins with newspaper twists of calcium carbide for 2–3 days before export in a Campinus warehouse.

Ethylene is also used successfully for ripening. At 20 °C Wills *et al.* (2001) found that the time to ripen of unripe mangoes increased linearly with logarithmic decrease in ethylene concentration over the range of less than 0.005, 0.01, 0.1, 1.0 and 10 µl L⁻¹. Other recommendations include

- 19–21 °C gave better quality characteristics than those ripened at 28–30 °C (Singh and Mathur 1952);
- 15.5–18.5 °C was satisfactory but the fruit were a little tart and required up to 3 days subsequent exposure to 21–24 °C to develop a good flavour (Hatton *et al.* 1965);
- 21–24 °C was recommended as the optimum ripening conditions (Hatton *et al.* 1965);
- 29–31 °C using ethylene at 10 µl L⁻¹ for 24 h in 85–90% r.h. (Wills *et al.* 1989).

Chaplin (1988) reported that treatment of immature fruit with ethylene led to softening but with poor flavour development.

Diseases

The main disease problem is infection of the fruit during development on the tree. Preharvest fungal infections by *Glomerella cingulata*, the conidial stage *Colletotrichum gloeosporioides*, cause anthracnose

disease. The spores of this organism may infect fruit, germinate, form appressoria which remain quiescent on the skin of the fruit until the fruit begins to ripen. The fungus then invades the cells of the fruit by hyphae growing from the appressorium resulting in the anthracnose disease. Fruit, especially those that are to be exported, are harvested at a stage of maturity where the fungus has not penetrated the fruit but is firmly fixed to its surface at the resistant appressorial stage. Therefore fruits, which look perfectly healthy at harvest, may develop the disease symptoms postharvest. Thompson (1987) reviewed preharvest sprays of mangoes to control anthracnose. Recommendations are for field application of chemical fungicides often followed by postharvest hot water treatment usually combined with a fungicide. In Florida (McMillan 1972) cupric hydroxide at 2.4 g L⁻¹ or tribasic copper sulphate at 3.6 g L⁻¹ plus the organic sticker Nu-Film 17 at 0.125% applied at monthly intervals at 57 L per tree from flowering to harvest gave good anthracnose control. Benomyl at 0.3 g L⁻¹ plus Triton B1956 at 0.15 ml L⁻¹ at 57 L per tree at monthly intervals from flowering to 30 days before harvesting was shown to be very effective against anthracnose on mangoes (McMillan 1973). Mancozeb, chlorothalonil and ferbam were shown to be equally effective as field sprays against mango anthracnose in Florida (Spalding 1982). Trials carried out on Keitt mangoes in South Africa showed that two preflowering applications of copper oxychloride and then two applications of Bayfidan (triadimenol) during flowering followed by monthly applications of copper oxychloride from fruit set ensured effective control of anthracnose (Lonsdale 1992a). Sprays were applied to run off at about 20 L per tree. In Australia mancozeb applied at 1.6 g L⁻¹ a.i. as a weekly spray during flowering then as a monthly spray until just before harvesting gave good control of mango anthracnose (Grattidge 1980). In studies in the Philippines field sprays with mancozeb or copper were effective in controlling mango anthracnose and superior to either captan or zineb (Quimio and Quimio 1974).

Soft brown rot of mangoes, caused by *Nattrassia mangiferae* in South Africa, is due to field infections that were shown to be controlled by applications of copper oxychloride in June (preflowering) and in January. Further applications after fruit set (between June and January) did not benefit the control of the disease (Lonsdale 1992b).

Stem-end rot of mangoes in Australia was shown to be caused by preharvest infections with *Dothiorella dominicana*, *D. mangiferae*, *Phomopsis mangiferae*, *Lasiodiplodia theobromae*, *Cytosphaeria mangiferae* or *Pestalotiopsis* sp. (Johnson *et al.* 1992a, 1992b). They also showed that these fungi occur widely on mature branches and, in certain conditions, colonize the inflorescence tissue as it matures thus reaching the stem end of fruit through the pedicel. These infections remained latent until after the fruit has been harvested or until the fruit on the tree became senescent. However, Johnson *et al.* (1992a, 1992b) found a higher level of stem-end rot caused by *D. dominicana* in a mango orchard that had been regularly sprayed with a copper fungicide than at another site that had not been sprayed. At the unsprayed site the mangoes were extensively diseased with anthracnose, which may have prevented *D. dominicana* infecting the fruit from the pedicel where it was detected.

Yenjit *et al.* (2010) assessed compounds obtained from extracts of the pericarp of *Areca catechu* L., *in vitro* and in mango fruit for antifungal activity against *Colletotrichum gloeosporioides*. *In vitro* studies indicated that some extracts could inhibit the mycelial growth. When applied to fruit some extracts were significantly more effective than benomyl for controlling postharvest anthracnose disease. Kefalew and Ayalew (2008) screened fungi and bacteria isolated from unmanaged mango trees in Ethiopia and found good control when they were tested *in vitro* against *C. gloeosporioides*. These were then tested *in vivo* on fruit and *Brevundimonas diminuta* and the yeast B-65-23 were found to be as effective as hot water treatment at 55 °C for 5 min, but they recommended further investigations on the safety of the isolates, particularly the bacteria, for use on edible fruit.

In the area of St Thomas in Jamaica, mango trees grown close to the prevailing wind from the sea had no disease what so ever. Those more inland protected from the prevailing wind had high levels of disease especially anthracnose.

Hot water treatment for anthracnose control

This was developed mainly to control anthracnose disease. Postharvest treatment of the fruit with fungicide is generally reported to be ineffective in controlling anthracnose disease (Prakash and Pandey

2000), but immersing them in hot water, preferably containing an appropriate fungicide, can give good disease control. There are various recommendations for successful treatments (Table 137).

In some cases it has been shown that there is an interaction between water temperature and fungicide, where at lower temperatures there is a greater need to add fungicide (Muirhead 1976). Control of anthracnose was achieved when a 30-s dip in 1000 µl L⁻¹ flusilazole was preceded by a 5-min dip in water at 55 °C but this treatment damaged the fruit. Good control of soft brown rot and anthracnose was achieved in Kent mangoes by dipping in water at 40 °C for 5 min followed by a 30-s dip in 3000 µl L⁻¹ flusilazole plus 1000 µl L⁻¹ prochloraz. Good control of the two postharvest rots was obtained in Sensation when the hot water treatment was followed by an application of unheated penconazole and prochloraz, each at 1000 mg L⁻¹, by dipping the fruit for 5 min in a mixture of 2000 mg L⁻¹ of penconazole and 500 mg L⁻¹ of prochloraz at temperature of 40–50 °C or by a 30-s dip in unheated 6000–8000 mg L⁻¹ of penconazole plus 2000 mg L⁻¹ of prochloraz. But the latter treatment resulted in poor colour development. Phytotoxicity resulted when Sensation mangoes were dipped for 5 min in 2500 mg L⁻¹ penconazole plus 1100 mg L⁻¹ prochloraz at temperature between 40 and 55 °C (Pelser and Lesar 1989).

Hot water treatment containing fungicide can also be effective in controlling stem-end rot caused by the fungus *Dothiorella dominicana* (Johnson *et al.* 1990a, 1990b). When preceded by a 5-min dip in water at 40 °C flusilazole controlled soft brown rot caused by *Hendersonia creberrima* in Kent during simulated export by sea (3 weeks at 10 °C followed by ripening at 20 °C) but did not control anthracnose rot (Johnson *et al.* 1990a, 1990b). Dessalegn *et al.* (2013) treated mango fruit with either salicylic acid or potassium phosphonate at 1000 mg L⁻¹ combined with dipping in a sodium bicarbonate at 51.5 °C solution for 3 min. Both treatments significantly reduced disease development compared to the sodium bicarbonate hot water treatment alone or those not treated. These combination kept anthracnose lesion development to below 5% and had 93.3% marketable fruit compared to the mean disease severity on untreated fruit that reached 100% with zero marketability within 12 days of storage.

Table 137 Recommended conditions for hot water treatments to control anthracnose disease on mango fruits (source: Thompson 1987)

Water temperature (°C)	Dipping time (min)	Fungicide ($\mu\text{L L}^{-1}$)	Country	References
51–51.5	15	0	USA	Pennock and Maldonaldo (1962)
54.4–55.8	5	0	USA	Smoot and Segall (1963)
55	5	0	USA	Hatton and Reeder (1965)
54.4	5	0	USA	Spalding and Reeder (1972)
53–55	5	0	Mexico	Lakshminarayana <i>et al.</i> (1973)
53	10	0	Philippines	Quimio and Quimio (1974)
55	5	0	Australia	Muirhead (1976)
50	30	0	Brazil	de Almeida Sampaio <i>et al.</i> (2008)
55	10	0	Brazil	de Almeida Sampaio <i>et al.</i> (2008)
53	5	0	West Indies	Crucifix <i>et al.</i> (1989)
51–55	30	0	Unknown	Carlos (1990)
52	30	0	India	Prakash and Pandey (2000)
51.5	5	500 benomyl	Australia	Muirhead (1976)
52	4	500 benomyl	Australia	Grattidge (1980)
53.5	4	500 benomyl	Australia	–
52	5	500 benomyl	Australia	Muirhead and Grattidge (1986)
55	5	1000 benomyl	South Africa	Jacobs <i>et al.</i> (1973)
54.4	5	1000 benomyl	USA	Spalding and Reeder (1972)
48.5	5	1000 benomyl	Australia	Muirhead (1976)
55	5	1000 benomyl	Brazil	de Almeida Sampaio <i>et al.</i> (2008)
58–62	2	2000 benomyl	Zambia	–
54.4	5	1000 thiabendazole	USA	Spalding and Reeder (1972)
55	5	1000 thiabendazole	Brazil	de Almeida Sampaio <i>et al.</i> (2008)
55	5	1350 captan	Brazil	de Almeida Sampaio <i>et al.</i> (2008)
55	5	1000 iprodione	South Africa	Brodrick and Thord Gray (1982)
55	5	2000–4000 kasugamycin	Brazil	Sampaio <i>et al.</i> (1983)
55	5	1000 benomyl plus 0.75 kGy irradiation	South Africa	Brodrick and Thord Gray (1982)
52	15	0.1% carbendazim or 0.1% thiophanate-methyl	India	Prakash and Pandey (2000)

The quarantine standard hot water treatment in Chile for fruit fly control was immersion at 46.5 °C for 65 min (Muñoz *et al.* 1998). It was found that fruits exposed to 50% CO₂ with 2% O₂ for 5 days or 70–80% CO₂ with less than 0.1% O₂ for 4 days controlled fruit fly infestations and the fruit did not suffer adverse effects when they were subsequently ripened in air (Yahia *et al.* 1989).

Hot water treatment on quality and damage

In studies by Thompson (1987) hot water treatment had little or no effect on the quality or marketable life of the fruit. In other work, the skin colour was improved by both hot water and vapour heat treatment (McGuire 1991, Jacobi *et al.* 1993, Coates *et al.* 1993a). Jacobi *et al.* (1993) observed little fruit injury in mangoes exposed to 46 °C even for 75 min and in a

comparison among hot water treatment, vapour heat treatment and untreated fruit the time to fruit softening was 3.6, 3.3 and 4.1 days, respectively. Hot water treatments at 52 °C for up to 30 min did not show any adverse effect on fruit ripening (Prakash and Pandey 2000). In contrast hot water treatment increased the rate of shrivelling and reduced the fruit firmness and acidity during subsequent storage (McIntyre 1993). Crucifix *et al.* (1989) and Crucifix (1990) also showed that exposure of Julie to 55 °C for 5 min resulted in scorch.

Mangoes that were treated with hot water postharvest were found to be susceptible to damage as a result of the treatment if it was applied within 24 h of harvesting if they were wet from rain (Coates *et al.* 1993a). Hot water treatment did not damage fruit if there was a delay of 48 h between harvest and

treatment, but this delay could affect the efficiency of the hot water in disease control. Mature Kensington fruits were incubated at 22–42 °C for 4–16 h prior to a hot water treatment of 45 °C for 30 min or 47 °C for 15 min by Jacobi *et al.* (2000). They were then ripening at 22 °C. Hot water injuries were reduced, and in some cases eliminated, by conditioning the fruits at 40 °C for 8 h. The conditioning temperature was more important than the duration of the hot water treatment in injury alleviation. Conditioning at 40 °C prior to hot water treatment accelerated fruit ripening, increased weight loss, reduced fruit firmness, increased °Brix and lowered TA compared to untreated fruits and fruits receiving other heat treatments, but made them more resistant to postharvest diseases.

Djioua *et al.* (2009) dipped Keitt mangoes in water at 50 °C for 30 min, cooled for them for 15 min, minimally processed them and stored them at 6 °C. This treatment maintained their acceptability for 6 days that was longer than those that were not treated.

Vapour heat treatment

This treatment was developed to control infections of fruit flies. It involves stacking the boxes of freshly harvested fruit in a room that is heated and humidified by the injection of steam. The temperature and exposure time are adjusted to kill all stages of the insects (eggs, larvae, pupa and adult) but not damage the fruit. The most difficult stage to control by hot water or vapour heat treatment is the larval stage because it tends to be further from the fruit surface and thus exposed to high temperatures for shorter periods (Jacobi *et al.* 1993). A recommended treatment is placing the fruit in an insulated room 43 °C in saturated air for 8 h, until the temperature at the centre of the fruit reaches 43 °C and then holding the temperature for a further 6 h. Merino *et al.* (1985) and Esquerro and Lizada (1990) described a method of control of oriental fruit fly in Carabao mangoes. This involved exposing the fruit to 46 °C and at least 95% r.h. The exposure time was judged by placing a temperature probe alongside the seed of a fruit and when it had reached 46 °C they were kept under those conditions for 10 min. This treatment also resulted in significant reductions in both anthracnose and stem-end rot diseases. A similar treatment was quoted by Coates *et al.* (1993a, 1993b) against Queensland fruit fly for Kensington

mangoes. However, McGuire (1991) found that hot water treatment at 46 °C was more effective than hot air treatment at either 46 or 48 °C with 58–90% r.h. in controlling both anthracnose and stem end rot. Coates *et al.* (1993a) found that vapour heat treatment did not control stem end rot but reduced anthracnose. To achieve complete control of anthracnose they found that it was necessary to apply a combination of vapour heat treatment (95% r.h. and above with a core temperature of 46.5 °C for 10 min) plus hot water plus benomyl (0.5 g L⁻¹ a.i.) at 52 °C for 5 min or a prochloraz ambient dip (0.25 ml L⁻¹ a.i.) replacing the benomyl. Vapour heat treatment had little effect on stem end rot of mangoes caused by *Dothiorella dominicana* and *Lasiodiplodia theobromae* (Coates *et al.* 1993a). Vapour heat treatment enhanced ripening of the cultivar Baneshan during 14 days of storage compared with the control, but it resulted in better marketability of fruits because of uniform peel colour development (Pal *et al.* 1999). Vapour heat treatment can cause injury to some fruits.

Physiological disorders

Jelly seed

A physiological disorder of mangoes called jelly seed can develop during storage and marketing of the fruit. The disorder starts in the mesocarp around the seed and progresses outwards towards the peel of the fruit. It forms a characteristic water-soaked appearance in the flesh, giving the fruit an offensive flavour and aroma. The cause of the disorder may be partially genetic since cultivars such as Tommy Atkins seem particularly susceptible. However, Mayne *et al.* (1993) have shown that jelly-seed in Tommy Atkins is associated with flowering time. They showed that delaying flowering by removing all the inflorescences from the tree greatly reduced jelly seed in fruit that developed from the subsequent flowering. These fruit were larger than those produced from trees where the inflorescences had not been removed but the number of fruit per tree was reduced.

Lenticel damage

In a study of lenticel damage on the cultivars Heidi, Sensation, Kent, Keitt, Tommy Atkins and Zill in South Africa Oosthuysen (1998) found that cool, humid or wet conditions on the date of harvest strongly favoured the postharvest occurrence of

lenticel damage. Conversely, dry, hot conditions discouraged its occurrence.

Carbon dioxide and oxygen injury

Symptoms of CO₂ injury during storage of mangoes involved irreversible inhibition of ripening upon transfer to air at the ripening-conducive temperature of 20 °C. Other symptoms include abnormal, greyish, epidermal colour, inhibition of normal aroma development and appearance of off-flavours. Injurious levels of CO₂ irreversibly inhibited the production of ethylene by inhibiting the enzyme ACC oxidase. Lower levels of CO₂ acted at the same sites to reversibly inhibit ethylene production. Low O₂ resulted in irreversible inhibition of ripening, especially chlorophyll degradation, which resulted in abnormal colour development and increased ethanol production. Injurious levels of O₂ inhibited the production of ethylene by the fruit in an irreversible manner by inhibiting the enzyme ACC synthase. Less extreme levels of O₂ acted at the same sites to reversibly inhibit ethylene production (Bender *et al.* 2000b).

Mangosteen

Guttiferae

Garcinia mangostana L. There is some controversy as to its origin but it is generally believed that it originated in Malaysia. Zeven and de Wet (1982) reported that it is derived from the wild species *G. silvestris* Boerl., which is found in both Malaysia and India. It is considered by some to be the most delicious of all fruits, not least by the author. It has been grown successfully, on a small scale, outside Southeast Asia and the Indian subcontinent including Costa Rica, Côte d'Ivoire, Ecuador, Madagascar and Panama.

The fruit, which are produced on small slow-growing trees, are subglobose in shape with a persistent calyx. They ripen to dark reddish purple colour often with brown scars and can be up to 8 cm in diameter. The skin is thick and tough and inside of which is white translucent flesh divided into five to eight segments. Each segment may or may not contain a seed. The anthocyanins in the outer pericarp mainly consisted of cyanidin-sophoroside, cyanidin-glucoside, cyanidin-glucoside-pentoside,

cyanidin-glucoside-X, cyanidin-X2 and cyanidin-X, where X denotes an unidentified residue of *m/z* 190, a mass which does not correspond to any common sugar residue. Cyanidin-3-sophoroside and cyanidin-3-glucoside were the major compounds and the only ones that increased with fruit colour development (Palapol *et al.* 2009). Total world production of mangoes, mangosteens and guavas in 2010 was estimated by FAO (2013) as 37,124,742 tonnes.

Harvesting

Harvest maturity is normally judged on the skin colour, which changes from green as it matures. The Malaysian Agricultural Research and Development Institute published a colour chart of changes in skin colour as a guide to harvest maturity. Wardlaw (1937) mentioned that fruit that were 'just ripening' at harvest did not appear to ripen normally and had hard flesh and poor flavour. Those picked fully ripe were of good appearance and flavour. In Indonesia Daryono and Sosrodiharjo (1986) found that the best time for harvesting was when 25% of the fruit skin had developed a purple colour. Sugar content, acidity, sugar:acid ratio and ascorbic acid content were 14.3%, 0.46%, 31.3 and 42.3 mg 100 g⁻¹, respectively, at harvest. Impact injury during harvesting and handling can damage the fruit. A drop of only 10 cm could cause slight pericarp damage resulting in hardening at the point of impact within 24 h. Higher drops caused significantly greater damage including aril collapse, dehydration, pink colour development or browning (Tongdee and Suwanagul 1989).

Prestorage treatments

Piriavinit *et al.* (2012) described experiments where fruit were harvested when the skin was light greenish yellow with scattered pinkish spots. These were exposed to 1 µl L⁻¹ 1-MCP for 6 h at 25 °C and then stored at 15 °C. The 1-MCP treatment temporarily delayed softening of the fruit flesh but their storage life at 15 °C, defined as the time until the pericarp was dark purple, was 27 days in the 1-MCP-treated fruit compared to 18 days in those that had not been treated.

Postharvest physiology

It is a climacteric fruit with ethylene production of about 29 nl kg⁻¹ h⁻¹. Their respiration rate was given as 21 mg (12 µl) CO₂ kg⁻¹ h⁻¹ at 25 °C (Rattanachinnakorn *et al.* 1996). Piriavinit *et al.* (2012) reported that 1-MCP treatment reduced ethylene production and reduced the levels of 1-aminocyclopropane-1-carboxylic (ACC) acid in the pericarp and the pericarp activities of ACC synthase and ACC oxidase. Dangcham *et al.* (2008) found that the increase in pericarp firmness during storage resulted from induction of lignin synthesis, associated with an increase in phenylalanine ammonia lyase (PAL) and peroxidase (POD) activity and gene expression.

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for 2–3 weeks (Mercantilia 1989) but in other work at room temperature of 27–30 °C and 50–60% r.h., 30% of the fruit was spoiled after 10 days and 100% after 20 days (Raman *et al.* 1971). Storage life, defined as the time until the pericarp was dark purple, was much longer at 15 °C than at 25 °C (Piriavinit *et al.* 2012). Augustin and Azudin (1986) showed that storage at either 4 or 8 °C could lead to hardening of the skin although the flesh may remain acceptable even after 44 days. Subsequently Dangcham *et al.* (2008) confirmed that chilling injury was expressed as pericarp hardening. Uthairatanakij and Ketsa (1996) also reported that storage at less than 10 °C could lead to rapid hardening and darkening of the pericarp when fruit were returned to ambient temperatures, although Daryono and Sosrodiharjo (1986) found that storage for 7 days at 5 °C caused no chilling injury and had no adverse effect on fruit quality. They also found that weight loss and percentage of diseased fruit after 7 days of storage at 5 °C were 3.3 and 23.9% at ambient temperature and 0 and 11% at 5 °C. Refrigerated storage recommendations include

- 4.5–7.0 °C and 80–90% r.h. for 30 days with 38% spoilage (Raman *et al.* 1971);
- 3.9–5.6 °C and 85–90% for 7 weeks (Pantastico 1975);
- 4 or 8 °C or for 42 days but fruit hardening occurred (Augustin and Azudin 1986);
- 5 °C and 90% r.h. for 6–7 weeks (Mercantilia 1989);

- 10 °C and 90% r.h. for 3–4 weeks (Snowdon 1990);
- 13.3 °C and 85–90% r.h. for 14–25 days (SeaLand 1991).

Storage in 5% O₂ + 5% CO₂ for 1 month resulted in best overall retention of the appearance of the peel and internal quality (Rattanachinnakorn *et al.* 1996). Daryono and Sosrodiharjo (1986) found that storage in PE bags slightly reduced the sugar:acid ratio in the fruit pulp but had no effect on the ascorbic acid content compared to storage without bags. However, the levels of weight loss and disease were greatly reduced when fruit were stored in polyethylene bags (Table 138).

Ripening

In Indonesia fruits ripened normally in 1 day at ambient temperature when harvested when 25% of the skin was purple (Daryono and Sosrodiharjo 1986). Fruit at different stages of maturity (light greenish yellow with 5% scattered pink spots to purple black) were harvested and kept at 25 °C and 85–90% r.h. Fruit from each maturity stage all developed to the final purple black stage. During the ripening pericarp firmness decreased significantly and TSS increased. Sensory evaluation and fruit colour, TSS and TA of fruit harvested at the different stages did not differ once the fruit had finally developed to the purple black stage (Palapol *et al.* 2009).

Transport

Wardlaw (1937) mentioned a trial shipment from Burma to the United Kingdom at 3.9–5.6 °C and 85–90% r.h. that took 30 days. Losses on arrival were measured at 40–55% mainly due to *Diplodia* spp. rots and rind hardening, but the remainder were in good condition and had a shelf life of 5 days at 12.8–15.6 °C.

Table 138 Effects of storage in PE bags on weight loss and disease of mangosteen fruit (source: adapted from Daryono and Sosrodiharjo 1986)

Type of polyethylene bag	Weight losses (%)	Diseased fruit (%)
None	7.2	22.3
Perforated polyethylene bags	2.3	16.1
Closed polyethylene bags	0.3	13.0

Diseases and disorders

Botryodiplodia theobromae, *Diplodia* spp., *Gloeosporium* sp., *Pestalotia flagisetula*, *Phomopsis* spp. and *Rhizopus* spp. have been reported infecting mangosteen fruit. Infection may harden the skin and cause decay of the aril (Morton 1987). Williams and Liu (1976) reported that fruit rot caused by *B. theobromae* was common in Sabah, and two other fungal pathogens occurred rarely. Sangchote and Pongpisutta (1997) reported that fruit rot fungi isolated in Thailand included *Lasiodiplodia theobromae*, *Colletotrichum gloeosporioides*, *Phomopsis* sp., *Gliocephalotrichum bulbilium*, *Pestalotiopsis* sp. and *Lasiodiplodia theobromae*. Dipping the fruits in 1000 ppm thiophanate-methyl for 3 min reduced the incidence of disease compared with untreated fruits.

Translucent flesh or translucent aril is a common physiological disorder. Fruits exhibiting translucent flesh disorder had higher rind and flesh water contents and lower TSS and TA compared to unaffected fruit. Specific gravity of translucent flesh fruit was greater than one and that of normal flesh fruit was less than one. Fruit specific gravity and natural transverse rind cracking were used to separate translucent-fleshed fruits from normal fruits. Translucent flesh may be associated with water infiltration during development since it could be induced in normal fruits following vacuum infiltration with water (Pankasemsuk *et al.* 1996). Images obtained by either X-rays or nuclear magnetic resonance were suitable for detecting internal disorders and rotten pulp in fruits and NMR imaging was able to identify translucent flesh disorder (Yantarasi *et al.* 1998).

Medlar

Rosaceae

Mespilus germanica L. Despite its specific name it probably originated in Asia Minor, Greece, the Black Sea coasts of modern Turkey or Iran and is found growing wild in northern Europe including Britain. It may have been cultivated for 3000 years in the Caspian Sea region of northern Iran. It was introduced to Greece around 700 BCE and to Rome about 200 BCE and was an important fruit during Roman and medieval times (Baird and Thieret 1989). It is a spreading deciduous tree or shrub that is thorny in the wild but thornless cultivars have been selected.

It can grow up to 8 m tall, but it is usually shorter and more like a shrub with a life span of 30–50 years. The fruit is five seeded and set in a receptacle with five conspicuous calyx lobes. They are brown subglobose or pyriform and crowned by foliaceous sepals. There are several cultivars with the cultivars Dutch or Monstrous bearing fruits that can be 5 cm in diameter. The cultivar Nottingham is said to have the best flavour and Royal and Stoneless being of poorer eating quality (Harrison *et al.* 1985).

Ripe fruit were reported to have a sugar content in the flesh of some 10.6% and a dry weight of 42% (Burton 1982). Nabavi *et al.* (2011) gave the following: total phenol $29.35 \pm 1.7 \text{ mg g}^{-1}$, total flavonoid $14.88 \pm 1.2 \text{ mg g}^{-1}$, DPPH (1,1-diphenyl-2-picryl hydrazyl) free radical scavenging IC_{50} $419 \pm 3.2 \mu\text{g ml}^{-1}$, nitric oxide scavenging IC_{50} $247 \pm 12.2 \mu\text{g ml}^{-1}$, H_2O_2 scavenging activity IC_{50} $1138 \pm 77.1 \mu\text{g ml}^{-1}$ and Fe^{++} chelating ability percentage or IC_{50} $23.0 \mu\text{g ml}^{-1}$. Glew *et al.* (2003) reported that the fruit have a high mineral content but especially potassium. Also they also found that the ascorbic acid and dry matter percentage showed a constant decline as the fruit matured and was the highest in immature fruits and the lowest in ripe fruits. They found that sucrose was highest at 1 week after harvest at $228.4 \text{ mg } 100 \text{ g}^{-1}$ fresh weight and then decreased to $1.4 \text{ mg } 100 \text{ g}^{-1}$ 4 weeks after harvest. Ayaz *et al.* (2002) found that the principal fatty acids in medlar fruit harvested from 157 to 187 days after flowering were mainly palmitic acid, linoleic acid and α -linolenic acid. While the content of palmitic acid and stearic acid increased, the content of linoleic acid and linolenic acid decreased as the fruit ripened and the pulp darkened. Linoleic acid was 60.0% and α -linolenic acid was 13.5% in ripe, hard fruits on a dry weight basis at 157 days after flowering which decreased throughout ripening to 28.7 and 5.6% of dry weight, respectively, in the fully softened and darkened pulp. Aydin and Kadioglu (2001) found that during the early stages of medlar fruit development, the level of ascorbic acid gradually decreased, then increased in the pre-ripening stage followed by a decrease in the post-ripening period. Polyphenol oxidase activity also gradually decreased during the early stages of development but increased in the post-ripening stage. The level of glucose gradually increased during fruit development and ripening, but pentoses, hexoses and soluble

Table 139 Changes in medlar fruit development in Turkey (source: adapted from Aydin and Kadioglu 2001)

Harvest date	Fruit diameter (cm)	Fruit maturity	Fruit colour
15 Jun 1999	1.8	Unripe	Fully green
15 Jul 1999	1.9	Unripe	Greenish
15 Aug 1999	2.1	Half ripe	Greenish, partly brownish
15 Oct 1999	2.2	Pre-ripe	Yellowish brown
15 Nov 1999	2.5	Post-ripe	Yellow-brown

proteins decreased during fruit development, then increased in the ripening stage. They concluded that the increase in PPO and peroxidase activities as well as in sugar and protein contents had an important role in reducing the astringency of medlar fruits.

Harvesting

Aydin and Kadioglu (2001) showed the changes in fruit development on the tree in Trabzon in Turkey 1 month after anthesis (Table 139). Ayaz *et al.* (2002) described fruit in Turkey as follows: 157 days after flowering fruit were ripe, skin light brown, hard, pulp white, 172 days after flowering fruit were ripe, skin partly dark brown, fruit table softened, pulp whitish and partly brownish and 187 days after flowering fruit were very ripe, skin fully dark brown, soft, pulp fully dark brown. In Britain the fruit does not become palatable until it is bletted, which means it is soft and brown and half rotten. In the countries of origin it can be ripened on the tree.

Storage

Harvesting is common carried out before they are fully ripe and they are then stored packed in straw until they are over ripe. Glew *et al.* (2003) reported that it was a climacteric fruit. Stoneless is a cultivar that is thought to store well.

Melon

Cucurbitaceae

Cucumis melo L. netted melons, *C. melo* L. (Reticulatus Group), commonly called cantaloupe or muskmelon (Bailey 1947). Cantaloupe netted melon

C. melo Reticulatus. cantaloupe netted melon *C. melo* Lymphothelialis. True cantaloupe, the Cantaloupensis Group, are non-netted fruit common to Cantaluppi, Italy. Honey dew *C. melo* Inodorus. Honey dew melon *Cucumis melo* L., (Inodorus Group) or Winter include honeydew, casaba, crenshaw and canary melons (Bailey 1947). Oriental sweet melons (*C. melo* var. *makuwa* Makino). *C. melo* is sometimes classified into two basic types: *reticulatus* group, which are the rough skinned netted or cantaloupe types, and *inodorus* group, which are smooth skinned and include the honeydew, casaba, crenshaw, charentais, hami, Persian, Spanish and santa claus types (Seymour and McGlasson 1993). They originated in Asia and Africa and were brought to Britain around the 16th century and were first introduced to the New World by Columbus during his second expedition. They were part of rations aboard the ships to help prevent scurvy in sailors. Once his men had eaten them and discarded the seeds, the crop quickly took hold in Haiti and spread from there. Seeds were also brought to California by Spanish Conquistadors. However, melons did not gain prominence as a common food until it was brought again during the slave trade. It is an indehiscent fleshy berry, usually spherical with a hollow central cavity containing many seeds. Ripe muskmelons will freeze at about -2.2 to -1.2°C (Wright 1942). The chemical content was given by USDA (2012) in Table 140. Total world production of other melons including cantaloupes in 2010 was estimated by FAO (2013) as 26,396,537 tonnes.

Harvesting

In melons when the leaf, in whose axis a fruit is borne, dies, then that fruit is judged to be ready for harvesting. In certain parts of the world TSS is used to specify maturity for example honeydew must have a minimum soluble solids content of 10%. In the mid-1990s an online machine was developed in Spain to measure the TSS of melon while they were passed along the grading line (Figure 109). It worked by the thin needle of a syringe being injected into the fruit, which withdrew a small sample of the juice that could be analysed and the fruit graded on the basis of the reading. There was some concern about possible perceived contamination of the fruit. Shining a light on a fruit and measuring the amount

Table 140 The composition of cantaloupe, casaba, honeydew melon fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	Cantaloupe	Casaba	Honeydew
Water (g)	90.15	91.85	89.82
Energy (kcal)	34	28	36
Protein (g)	0.84	1.11	0.54
Total lipid (fat) (g)	0.19	0.10	0.14
Carbohydrate, by difference (g)	8.16	6.58	9.09
Total dietary fibre (g)	0.9	0.9	0.8
Total sugars (g)	7.86	5.69	8.12
Calcium (mg)	9	11	6
Iron (mg)	0.21	0.34	0.17
Magnesium (mg)	12	11	10
Phosphorus (mg)	15	5	11
Potassium (mg)	267	182	228
Sodium (mg)	16	9	18
Zinc (mg)	0.18	0.07	0.09
Total ascorbic acid (mg)	36.7	21.8	18.0
Thiamine (mg)	0.041	0.015	0.038
Riboflavin (mg)	0.019	0.031	0.012
Niacin (mg)	0.734	0.232	0.418
Vitamin B-6 (mg)	0.072	0.163	0.088
Folate (µg DFE)	21	8	19
Vitamin B-12 (µg)	0.00	0.00	0.00
Vitamin A (µg RAE)	169	0	3
Vitamin A (IU)	3382	0	50
Vitamin E (α-tocopherol) (mg)	0.05	0.05	0.02
Vitamin D (D2 + D3) (µg)	0.0	0.0	0.0
Vitamin D (IU)	0	0	0
Vitamin K (phylloquinone) (µg)	2.5	2.5	2.9
Fatty acids, total saturated (g)	0.051	0.025	0.038
Fatty acids, total monounsaturated (g)	0.003	0.002	0.003
Fatty acids, total polyunsaturated (g)	0.081	0.039	0.059

transmitted can also be used to measure their soluble solids content. The transmission of near-infrared light has also been used as a non-destructive method for measuring the TSS content of cantaloupe melons (Dull *et al.* 1989). A simpler method is to tap the fruit with the knuckle in the field to judge whether they are ready to be harvested. The sound changes as they mature. Consumers when purchasing melons sometimes use the method of testing maturity.

As part of the natural development of fruit an abscission layer is formed in the pedicel, which is



Figure 109 Melon packhouse in Spain showing the equipment for automatic measurement of total soluble solids. (Photo: Fernando Cosman.) See colour plate section.

referred to as *slip*. In cantaloupe melons, harvesting before this abscission layer is fully developed results in inferior flavoured fruit compared with those left on the vine for the full period (Pratt 1971). However, fruit harvested at this full maturity will have only a short marketable life. The method is described as follows:

- Non-slip, fruits fully grown, but still firmly attached.
- Half slip, abscission layer beginning to form with an obvious crack at the junction.
- Full slip green, crack quite distinct, circling the whole stalk and can be broken with gentle pressure.
- Full slip yellow, abscission complete and the fruit soft, fully yellow, with a distinct aroma.

Neri and Brigati (1996) found that skin colour was a good indicator of maturity, while for the cultivars Harper and Symphony, flesh colour was equally effective. For Soleado, fruit firmness was also a good indicator of maturity. For all cultivars TSS was a suitable indicator of harvest maturity, but it is destructive. In experiments described by Moelich *et al.* (1996), galia 5 fruits were harvested less than 10% yellow colour break, 10–20% yellow colour break and 50–70% yellow colour break, and stored at 2 °C for up to 26 days. Fruits with less than 10% yellow and 10–20% yellow fruits showed no senescent breakdown during storage, but failed to develop sufficient colour to be acceptable in the market place. Galia 5 with 50–70% yellow developed unacceptable levels of senescent breakdown. It was concluded

that galia 5 is not suitable for normal sea freight export from South Africa to Europe. Doral fruits harvested 31 and 35 days after anthesis were stored at 12 °C for up to 33 days. The first evidence of senescent breakdown appeared after 21–25 days of storage. Fruits harvested 31 days after anthesis were of acceptable internal quality, but fruits harvested 35 days after anthesis showed unacceptable levels of senescent breakdown after storage for 4 weeks at 12 °C.

Prestorage treatments

Hot water dipping was not effective in controlling postharvest diseases. With the cultivar Galia F1 hot water at 55 °C for 90 s resulted in high fungal infections after subsequent storage at 2 °C and 85–90% r.h. *Alternaria* spp., *Penicillium* spp., *Cladosporium* sp., *Mucor* spp., *Botrytis cinerea* and *Aspergillus* spp. were found to be present in infected fruits. Fruit softening was also quicker in the hot-water-treated fruits (Halloran *et al.* 1999). Hot water brushing was shown to remove soil, dust and fungal spores from the fruit surface, and partially or entirely sealed natural openings in the epidermis. It did this by smoothing the epicuticular waxes and thus covered and sealed stomata and cracks on the fruit surface, which could have served as potential pathogen invasion sites. The optimal hot water brushing treatment to reduce decay while maintaining fruit quality on Galia was 59 °C for 15 s or 56 °C for 20 s (Fallik 2004). The hot water brushing treatment at 56 °C did not cause surface damage and did not influence fruit weight loss or internal quality parameters.

Sivakumar and Korsten (2007) investigated the possibility of replacing SO₂ fumigation as a postharvest treatment with 1-MCP on the cultivar McLean's Red. They simulated export marketing conditions by fumigation with a moderate concentration of 1-MCP for 3 h and then stored them at 4 °C in CA for 21 days followed by packaging in MA and storage at 10 °C. They found that fungal decay was controlled and their natural colour was retained in fruits with these treatments. Those stored in 3% O₂ + 7% CO₂ had a deep red colour but showed limited yeast decay and the TSS, acidity and ascorbic acid contents were only slightly reduced. De Reuck *et al.* (2009a) packed

Mauritius and McLean's Red fruits in biorientated PP bags and exposed them to 1-MCP at 300, 500 or 1000 nl L⁻¹ within the packaging, heat sealed them and stored at 2 °C for up to 21 days. This combination of treatments was effective in preventing browning and retention of colour in both cultivars. 1-MCP significantly reduced the polyphenol oxidase and peroxidase activity, retained membrane integrity, anthocyanin content and prevented the decline of pericarp colour during storage. At higher concentrations than 300 nl L⁻¹ 1-MCP fruit showed negative effects on membrane integrity, pericarp browning, polyphenol oxidase and peroxidase activity in both cultivars, but at 1000 nl L⁻¹ there was a significant suppression of respiration rate and better retention of their TSS, acidity and firmness.

Postharvest physiology

Pratt (1971) showed that both Honeydew muskmelons and PMR-45 cantaloupes were climacteric and all melons were classified as being climacteric by Wills *et al.* (1989), but Biale (1960) classified all melons as non-climacteric, which was supported for muskmelons by (Obando *et al.* 2007). Exposing Honeydew melons to ethylene at 20 °C for 24 h reduced the incidence of chilling injury during subsequent storage at 2.5 °C compared to melons which had not been exposed to ethylene before storage (Lipton *et al.* 1979). This is presumably a ripening effect and the riper the melons the less susceptible they were to chilling injury.

Storage

Precooling is not commonly necessary but they can be hydrocooled. Susceptibility to chilling injury varies between cultivars and is a time temperature factor. For example Lutz and Hardenburg (1968) showed that periods of more than 15 days at 2.2–4.4 °C were required to injure cantaloupes. They also showed that the harvest maturity affected susceptibility to chilling injury with the less mature fruit being more susceptible. Symptoms of chilling injury were surface breakdown, softening, decay and the production of off-flavours especially when removed to higher temperatures. Refrigerated storage recommendations include

Cantaloupe type (*reticulatus* group)

- 0 °C and 85–90% r.h. for 2 weeks (Phillips and Armstrong 1967);
- 0–1 °C and 85–90% r.h. for up to 7 weeks (Anonymous 1967);
- 2.2–4.4 °C and 85–90% r.h. for 15 days ($\frac{3}{4}$ to full slip) (Lutz and Hardenburg 1968, Anonymous 1968);
- 0–1.1 °C and 85–90% r.h. for 1 week (Lutz and Hardenburg 1968);
- 0–1.7 °C and 85–90% r.h. for 5–14 days (full slip) (Anonymous 1968, Lutz and Hardenburg 1968);
- 1.7–3.3 °C and 85–90% r.h. for 10 days with 7.2% loss (Pantastico 1975);
- 3–4 °C and 85–90% r.h. for 6–12 days depending on cultivar (Tindall 1983);
- 3–5 °C and 85–90% r.h. for 10–14 days (Mercantilia 1989);
- 4–5 °C and 90% r.h. for 1–3 weeks (Snowdon 1990);
- 4.4 °C and 85–90% r.h. for 10–14 days (SeaLand 1991).

Honeydew type (*inodorus* group)

- 7.2 °C and 85–90% r.h. for 2–3 weeks (Honeydew) (Phillips and Armstrong 1967);
- 7.2–10 °C and 85–90% r.h. for 2 weeks (Crenshaw, Persian), 3–4 weeks (Honeydew) and 4–6 weeks (Casaba) (Anonymous 1968, Lutz and Hardenburg 1968);
- 7.2 °C and 85% r.h. for 4–5 weeks (Honeydew) (Pantastico 1975);
- 10–14 °C and 85–90% r.h. for 16–20 days (Honey) (Mercantilia 1989);
- 6–9 °C and 85–90% r.h. for 10–14 days (Net) (Mercantilia 1989);
- 6–7 °C and 85–90% r.h. for 10–14 days (Ogen) (Mercantilia 1989);
- 5–10 °C and 90% r.h. for 1–4 weeks (melons) (Snowdon 1990);
- 6 °C (Ogen, Galia) (Snowdon 1990);
- 10–15 °C and 90% r.h. for 3 weeks for Honeydew from South Africa (Snowdon 1990);
- 5 °C and 90% r.h. for 2–4 weeks for Honeydew from the United States (Snowdon 1990);
- 10 °C and 85–90% r.h. for 21–28 days (SeaLand 1991);

- 10 °C and 85–90% r.h. for 14–21 days (Persian) (SeaLand 1991).

Controlled atmosphere storage

Recommended CA conditions include 10–15% CO₂ and 3–5% O₂ for cantaloupe and 5–10% CO₂ with 3–5% O₂ for Honeydew and Casaba (SeaLand 1991). Kader (1985, 1992) recommended 3–7 °C with 10–15% CO₂ and 3–5% O₂ for cantaloupes which had a good effect but limited commercial use. For Honeydew Kader (1985, 1992) recommended 10–12 °C with 0% CO₂ and 3–5% O₂ which had a fair effect but was of no commercial use. Saltveit (1997) recommended 5–10 °C with 10–20% CO₂ and 3–5% O₂ which had only a slight effect.

Ripening

Exposing muskmelon cultivars to ethylene was said to be of no practical use since they are 'adequately self-ripening' (Pratt 1971). Recommended ripening temperatures for honeydew melon were 18–21 °C using ethylene at 10 µl L⁻¹ for 24 h in 85–90% r.h. and for cantaloupe melons 18–21 °C with no ethylene (Wills *et al.* 1989). Wardlaw (1937) recommended exposing fruit to 500 µl L⁻¹ ethylene. Pantastico (1975) found that fruit ripened evenly at 21 °C when exposed to ethylene at either 1000 or 5000 µl L⁻¹ for 18–24 h.

Monstera**Araceae**

Monstera deliciosa Liebm. Other common names include Mexican breadfruit, fruit salad plant and Swiss cheese plant. It is native of the tropical American forests of Mexico and Central America. It is a creeping vine that can grow up to 20 m long and has large, heart-shaped leaves and it flowers about 3 years after planting. The fruit is a spadix covered by hexagonal plates with a green skin colour turning yellow when ripe. They are up to 25 cm long and contain a soft white pulp. It can take over a year for the fruit to be ripe and at this stage the caps of the fruitlets at the base start to spread and show a creamy colour between them. When fully ripe the fruit are detached

at the slightest touch. No information could be found on harvesting them immature and ripening them, but immature fruit contain calcium oxalate crystals that can irritate the mouth and throat.

To improve their flavour after harvest, the fruit can be placed the fruit in a paper bag in a warm position and in a day or so the green caps will fall from the ripened section at the base of the fruit and expose the edible portion beneath. The section where the caps have not been shed and the small black scales between the edible segments within the fruit can result in severe irritation of the throat if eaten because of the presence of oxalate. The unripe section can be left in the paper bag until the next portion is ready to eat. Alternatively, the whole fruit can be ripened for eating at one time by standing the base in water and keeping it in the dark for a few days (Bruhl 2002).

Mora

Rosaceae

Rubus glaucus Benth., also called Andes berry. Perkins-Weazie (2002c) referred to the whitebark raspberry as *R. glaucus* L. and identified it as a South American tetraploid black raspberry. Mora originated in the Andean region of South America and is very popular in Colombia where they are eaten fresh and used in drinks, ice cream and a variety of puddings. It is a vigorous shrub with canes growing up to 3 or 4 m high that are covered with small hooked prickles. The fruit is a collection of drupes up to 2½ cm long with a sweet aromatic flavour (Kennard and Winters 1960) (Figure 110). The fruit is probably non-climacteric. They are normally harvested, with their receptacle still in place, as they change colour from light to dark red. Harvesting is by hand. Lutz and Hardenburg (1968) recommended 0 °C with 85–90% r.h. for 1–2 weeks. No other specific information could be found on their postharvest life, but from the author's observations in Colombia they appear to have a similar storage life to blackberries (*R. ulmifolius*).

Mountain damson

Simaroubaceae

Simarouba amara, also called bitter damson. It is native to the rainforests and savannahs of south and



Figure 110 Mora fruit ready for harvesting in Colombia.

Central America from Guatemala in the north to Bolivia in the south and from Ecuador in the west to the east coast of Brazil and has become naturalized in the Caribbean islands. The tree is a dioecious evergreen that grows up to 35 m high and has small yellow flowers.

Mulberry

Moraceae

Morus nigra L. It probably originated in western Asia, but has been grown in Europe from ancient times and is referred to by both Greek and Roman writers. The fruit is the swollen calyxes and are produced on deciduous trees that grow up to 9 m high. The fruits are green as they develop then turn red as they begin to mature and dark purple or black when fully mature. The White Mulberry (*M. alba* L.) is a native of China, whose fruit are white, pink or purple and taste sweet and a bit insipid, is grown mainly for its leaves, which are used as the food for the silk worm. Burton (1982) gave its sugar content as 8.1% and the dry weight 54%. The chemical content was given by USDA (2012) in Table 141. The fruits must be harvested when they are fully ripe, but at this stage they are very juicy and easily squashed. Harvesting is actually best done by

Table 141 The composition of mulberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.68 g	Thiamine	0.029 mg
Energy	43 kcal	Riboflavin	0.101 mg
Protein	1.44 g	Niacin	0.620 mg
Total lipid (fat)	0.39 g	Vitamin B-6	0.050 mg
Carbohydrate, by difference	9.80 g	Folate	6 µg DFE
Total dietary fibre	1.7 g	Vitamin B-12	0.00 µg
Total sugars	8.10 g	Vitamin A	1 µg RAE
Calcium	39 mg	Vitamin A	25 IU
Iron	1.85 mg	Vitamin E	0.87 mg
		(α-tocopherol)	
Magnesium	18 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	38 mg	Vitamin D	0 IU
Potassium	194 mg	Vitamin K	7.8 µg
		(phylloquinone)	
Sodium	10 mg	Fatty acids, total saturated	0.027 g
Zinc	0.12 mg	Fatty acids, total monounsaturated	0.041 g
Total ascorbic acid	36.4 mg	Fatty acids, total polyunsaturated	0.207 g

collecting the fruit from the ground when they have fallen from the tree. No information could be found on storage, but its postharvest life is very short and this has limited its commercial exploitation in spite of the fruit being delicious when fully mature.

Mume

Roseceae

Prunus mume Siebold & Zucc. Other common names include Chinese plum and Japanese apricot. The fruit is a drupe that has a thin skin and juicy flesh with a single hard seed in the middle. They are eaten fresh, used for liqueur production or pickling.

Harvesting

In Japan they are usually harvested at the mature green stage in June (Miyazaki 1983). Fruits of seven cultivars were harvested at 5-day intervals during maturation so that changes in the colour of the stone surface could be monitored. When embryos were immature, the stone surface was white-yellow in colour. It then changed to light brown as the embryos matured and finally to brown. The colour

did not differ significantly between cultivars. No significant yearly fluctuations in stone surface colour were observed in cultivar Nanko harvested at intervals in three successive years (Ishizawa *et al.* 1995). Goto *et al.* (1988) showed that the fruits harvested early were less sensitive to chilling than those harvested late. They also reported that the surface colour of the stone might be a useful criterion for assessing harvesting time. A shaker–harvester was developed, which was mounted on a 2-horse power engine and caused fruits to drop by vibration. It was shown to reduce working hours by 35% and costs by 41% compared with conventional methods.

Prestorage treatments

Lu *et al.* (2000b) tested several treatments for improving storage at 1 °C or room temperature and found that an ethylene absorbent was the most effective, followed by gibberellic acid treatment at 20 or 40 mg L⁻¹ and 2% CaCl₂. Baba and Ikeda (2003) found that storage of fruit for 5 days in high pressures of 0.5 MPa reduced their respiration rate, ethylene production and water loss. It also reduced skin pitting and browning, symptoms of chilling injury and delayed peel colour development.

Postharvest physiology

Lu *et al.* (2000b) and Koyakumaru *et al.* (1995) referred to mume as a *climacteric fruit*. Ethylene production rates were suppressed at high CO₂ concentrations or at O₂ levels of less than 5%. In 3% O₂, ethylene production rates peaked half day or 1 day after the respiratory climacteric peak (Koyakumaru *et al.* 1995). Ethylene production and yellowing of peel decreased with increasing maturity at harvest (Goto *et al.* 1988).

Storage

At an average temperature of 22 °C their shelf life is only 2 or 3 days (Miyazaki 1983). During storage at 0 or 5 °C chilling injury occurred as surface pitting and/or peel browning (Iwata and Yoshida 1979). CA storage was reported by Kaji *et al.* (1991) to increase their storage life at 20 °C and 100% r.h. as follows:

- 2–3% O₂ with 3% CO₂ for 15 days;
- 2–3% O₂ with 8% CO₂ for 15 days;

- 2–3% O₂ with 13% CO₂ for 19 days;
- 2–3% O₂ with 18% CO₂ for 12 days.

Baba and Ikeda (2003) stored mume fruit at various high pressures and their results indicated that long-term high-pressure storage at 0.5 MPa reduced respiration rate, ethylene production, water loss and prolonged their postharvest life. Fruits held at O₂ concentrations of up to 1% developed browning injury and produced ethyl alcohol at a high rate, the percentage of fruits with water-core injury was high in storage in low O₂ and no CO₂. Storage recommendations by Koyakumar (1997) were as follows:

- 10°C with 4–5% O₂ and 8–9% CO₂ for mature-green Hakuoukoume.
- 25°C with 3–4% O₂ and 10% CO₂ delayed the respiratory climacteric rises slightly and increased ethyl alcohol production after the third day of storage.
- 25°C with 3–5% O₂ and 9–10% CO₂ combined with an ethylene scrubber was effective in preserving fruit quality during a 10-day storage period.

Modified atmosphere packaging

Mature green Japanese apricots could be stored in sealed plastic film bags for at least 9 days at 20°C but showed increasing physiological damage when the CO₂ levels exceeded 20%. Putting an ethylene absorbent inside the bags greatly reduced levels of physiological damage (Osajima *et al.* 1987). Sealed packaging fruits in polyethylene, which reduced the O₂ level in the bags to 1–4%, and ethylene removal, extended the shelf life by 2 and 4 days, respectively, compared with no packaging. An O₂ level of less than 0.5% in the sealed bags caused metabolic abnormality in the fruits (Miyazaki 1983). Sealed packaged fruits using linear low-density polyethylene film of 30 µ thick with an ethylene scrubber had a shelf life of 12 days at 20°C (Kaji *et al.* 1991). In the sealed permeable film pouches containing 1 kg of fruit, the atmosphere contained 3–4% O₂ and 15% CO₂, whereas in the sealed non-permeable film pouches, the O₂ concentration was around 2%, but the CO₂ concentration varied depending on the film (>20% for PE and 10% for polymethylpentene). In sealed permeable film pouches, fruits ripened normally and few disorders were observed (Asami and Aoyagi 1997). Sealing the fruit in PE bags or storage in 5%

CO₂ prevented or reduced chilling injury, and the use of perforated PE bags delayed it (Iwata and Yoshida 1979).

Nance

Malpighiaceae

Byrsonima crassifolia (L.) Kunth synonymous with *Malpighia crassifolia* L. Other common names include nanche, chacunga, changunga, craboo, kraabu, savanna serrette and golden spoon. It is native to tropical America from central Mexico, through Central America, to Peru, Bolivia and Brazil, it also occurs in Trinidad, Barbados, Curaçao, St. Martin, Dominica, Guadeloupe, Puerto Rico, Haiti, the Dominican Republic and throughout Cuba and the Isle of Pines. The nance is limited to tropical and subtropical climates. In Central and south America, the tree ranges from sea-level to an altitude of 1800 m and cultivated along the coastal areas of Mexico. It is highly drought tolerant. It is valued for its small, sweet, yellow fruit, which are strongly scented. It is a slow-growing large shrub or tree up to 10 m high. Fruits showed a non-climacteric pattern of respiration (Camacho-Hernández *et al.* n.d.). Camacho-Hernández *et al.* (n.d.) reported that the roots, bark, flower, leaf and fruit have shown biological activity against dysentery and fever and their fatty acids are important because of their potential in preventing chronic disease.

Medina-Torres *et al.* (2004) studied quality indices of the fruit characteristics from eight selections to determine optimum harvest maturity of nance. The TSS:TA gave the best index on all eight selections and they proposed the following classification (i) 5.1–8 as sour fruit (sour-small and purple selections), (ii) 8.1–10 as sweet-sour fruit (conical, improved, sweet-sour#1, sweet-sour#2 and sweet-sour#3 selections) and (iii) greater than 10 as sweet fruit (sangunga selection). Camacho-Hernández *et al.* (n.d.) reported that skin colour was used to estimate harvest maturity and compared harvesting at the green turning and the yellow stage and then stored for 7 days at 20°C and 90% r.h. TSS in yellow stage fruits was 10.8 and green turning was 10.2 mg 100 g⁻¹ while ascorbic acid content was high in both fruit maturities: 140.82 g in yellow stage and 150.27 mg 100 g⁻¹ in green turning.

Naranjilla

Solanaceae

Solanum quitoense Lam. Other common names include Lulo and Toronja. Suarez and Duque (1992) referred to Lulo as *S. vestissimum*. It originated in Ecuador where it is found throughout the country from the Colombian border to the Loja province in the south. In Colombia, the main production area is located between Cali and Ipiales. It grows in the humid valleys of the Andes at an altitude between 1200 and 2100 m. The fruit are borne on semi-perennial woody shrubs that grow up to 2 m high and have thorny stems, large leaves and white flowers (dos Santos and Nagai 1993). The fruit is a globular berry with a persistent calyx and up to 7 cm in diameter. They are green as they develop and turn yellow or bright orange as they mature. The prickly short brown hairs in the skin surface are usually rubbed off for marketing. The pulp is juicy, green and acid, which somewhat resembles that of pineapple and guava in flavour, and has numerous small seeds embedded in it. The fruits are eaten raw or used for juices or preserves. It is a popular fruit in the Andean region, especially Colombia, and small quantities are exported to Europe and North America.

Suarez and Duque (1992) showed that ripening was characterized by a significant increase in the amount of esters, mainly butyl acetate, methyl (E)-2-butenate, 3-methylbutyl acetate, methyl (E)-2-methyl-2-butenate, methyl hexanoate, (Z)-3-hexenyl acetate and methyl benzoate. A significant increase in linalool and alpha-terpineol concentrations was also observed, as well as a moderate increase in geraniol, hotrienol and nerol concentrations. (Z)-3-Hexenol only increased significantly after the fourth ripening stage. In contrast, beta-myrcene, limonene and terpinolene showed a slight decrease in their concentrations with increasing maturation. Detected aliphatic hydrocarbons showed irregular variations in their concentration and aldehydes a slight increase. The chemical content was given by USDA (2012) in Table 142.

Harvesting is by hand and is based on the skin colour. They are usually harvested when the skins have begun to turn a yellowish-orange colour. At room temperature in Colombia (24–26 °C and 40% r.h.) they lost weight rapidly and became discoloured

Table 142 The composition of naranjilla fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	93.05 g	Sodium	4 mg
Energy	25 kcal	Zinc	0.10 mg
Protein	0.44 g	Total ascorbic acid	3.2 mg
Total lipid (fat)	0.22 g	Thiamine	0.045 mg
Carbohydrate, by difference	5.90 g	Riboflavin	0.000 mg
Total dietary fibre	1.1 g	Niacin	1.450 mg
Total sugars	3.74 g	Vitamin B-6	0.107 mg
Calcium	8 mg	Folate	3 µg DFE
Iron	0.35 mg	Vitamin A	28 µg RAE
Magnesium	11 mg	Vitamin A	568 IU
Phosphorus	12 mg	Vitamin E (α-tocopherol)	0.75 mg
Potassium	200 mg	Vitamin K (phylloquinone)	14.6 µg

(Amezquita 1973). Refrigerated storage recommendations include

- 10 °C and 90% r.h. for 1 week with no deterioration (Amezquita 1973);
- 7–10 °C and 90% r.h. for 4–6 weeks (Snowdon 1990).

Nectarines

Rosaceae

Prunus persica L. Batsch, *P. persica* var. *nectarina*. They have common origin with peach in China and are widely grown in temperate regions from China through India, Iran, Levant and the Mediterranean area. Naturalized populations are found that are relics of ancient cultivation of both peaches and nectarines (Harrison *et al.* 1985). The fruit is a drupe and is borne on a deciduous temperate zone tree, which is classified as climacteric. It is the same species as the peach and shares a lot of its postharvest characteristics. The chemical content was given by USDA (2012) in Table 143. Total world production for peaches and nectarines in 2010 was estimated by FAO (2013) as 20,528,283 tonnes.

Harvesting

Determination and prediction of harvest maturity is based on parameters such as flesh firmness, background colour and soluble solids. The 'Twist Tester',

Table 143 The composition of nectarine fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.59 g	Thiamine	0.034 mg
Energy	44 kcal	Riboflavin	0.027 mg
Protein	1.06 g	Niacin	1.125 mg
Total lipid (fat)	0.32 g	Vitamin B-6	0.025 mg
Carbohydrate, by difference	10.55 g	Folate	5 µg DFE
Total dietary fibre	1.7 g	Vitamin B-12	0.00 µg
Total sugars	7.89 g	Vitamin A	17 µg RAE
Calcium	6 mg	Vitamin A	332 IU
Iron	0.28 mg	Vitamin E (α-tocopherol)	0.77 mg
Magnesium	9 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	26 mg	Vitamin D	0 IU
Potassium	201 mg	Vitamin K (phyloquinone)	2.2 µg
Sodium	0 mg	Fatty acids, total saturated	0.025 g
Zinc	0.17 mg	Fatty acids, total monounsaturated	0.088 g
Total ascorbic acid	5.4 mg	Fatty acids, total polyunsaturated	0.113 g

developed at Massey University in New Zealand, measures firmness as crush strength by radial movement of a small calibrated blade at any point within the non-peeled fruit. The system was devised by Griessel (1995) where the differences in rate of softening between the inner and outer mesocarp were used in the determination and prediction of harvest maturity for the cultivar May Glo. In Turkey flesh firmness and soluble solids appeared to be the best practical methods for determining harvest maturity. Firmness values for minimum harvest maturity were 12–13 lbs. for the cultivar Nectared-6 and 12 lbs. for Independence. When combined with soluble solids, a firmness of 14–15 lbs. with minimum soluble solids of 11% was suitable for determining minimum acceptable maturity for Nectared-6, and 15–16 lbs. with a minimum of 10.5% soluble solids for Independence (Ozelkok *et al.* 1997). Pérez-Marín *et al.* (2009) evaluated commercially available spectrometers on the cultivar Sweet Lady both during ripening on the tree and storage at 0 °C and 95% r.h. They made calibration equations to quantify changes in fruit TSS, firmness, weight and diameter. They found that changes in these parameters could be measured non-destructively in seconds, with a single

Table 144 Ethylene production and respiration rate of nectarine fruit at different temperatures (source: adapted from Crisosto and Kader 2002c)

Temperature (°C)	Ethylene (µl C ₂ H ₄ kg ⁻¹ h ⁻¹)	Respiration rate (mg CO ₂ kg ⁻¹ h ⁻¹)
0	0.01–5	4–6
5	0.02–10	–
10	0.05–50	16–24
20	0.10–160	64–110

spectrum measurement both on the tree and during storage, paving the way for using the hand-held instruments to assist growers in making harvesting decisions in the field.

Postharvest physiology

The fruit is classified as climacteric. Ethylene production was given by Crisosto and Kader (2002c) for the lower end of the range of fruit that were mature but still unripe (Table 144). They found that there were higher respiration rates for ripe fruit and in general, nectarines harvested at the well-mature or riper stages will ripen properly without exogenous ethylene application. In some cultivars, exposure to 100 µl L⁻¹ ethylene results in more uniform ripening of fruit picked at the 'US mature' stage.

Storage

Chilling injury occurred after storage at 0 °C for 4 weeks in the cultivar Flavortop and resulted in the flesh having a woolly texture (Zhou *et al.* 2000). Both delayed storage, fruits held for 48 h at 20 °C before storage, and controlled atmosphere storage in 10% CO₂ with 3% O₂ alleviated or prevented chilling injury during storage at 0 °C. Control fruits showed 80% chilling injury during ripening after 4 weeks at 0 °C and 100% after 6 weeks. Delayed storage and controlled atmosphere storage were similar in their beneficial effect after 4 weeks but controlled atmosphere storage was better after 6 weeks. Delayed storage initiated ripening, which appeared to be the mechanism by which woolliness was prevented in that case (Zhou *et al.* 2000). Hardenburg *et al.* (1990) stated that storage recommendations are similar to peach for temperature and controlled atmosphere storage. At room temperature of 20 °C and 60% r.h. the fruit could be kept for 1–2 days (Mercantilia

1989). Specific refrigerated storage recommendations include

- -1 to 0°C and 85–90% r.h. for 3–7 weeks (Anonymous 1967);
- 0°C and 90–95% r.h. for 14 days (Mercantilia 1989);
- 2°C for 7 days (Mercantilia 1989);
- 4°C for 5 days (Mercantilia 1989);
- -1 to 0°C and 90–95% r.h. for 2–7 weeks (Snowdon 1990).

Controlled atmosphere storage

CA recommendations include

- $0-5^{\circ}\text{C}$ with 5% CO_2 and 1–2% O_2 or $0-5^{\circ}\text{C}$ with 3–5% CO_2 and 1–2% O_2 which had a good effect, but limited commercial use (Kader 1985);
- 5% CO_2 and 2.5% O_2 for 6 weeks (Hardenburg *et al.* 1990);
- -0.5°C with 90–95% r.h. with 5% CO_2 and 2% O_2 for 14–28 days (SeaLand 1991);
- 10% O_2 and 10% CO_2 for the cultivars Flavortop and Flamekist for up to 6 weeks (Lurie 1999).

When fruits from two harvests of Flamekist were stored in controlled atmosphere for 6 or 8 weeks, the fruit from the first harvest was of better quality after poststorage ripening. Although a 10% O_2 , 10% CO_2 atmosphere prevented internal breakdown and red-ening, fruit after extended storage did not develop the increased soluble solids content or extractable juice during poststorage ripening that occurred in non-stored fruit. Therefore, controlled atmosphere while prevent storage disorders did not prevent the loss of ripening ability occurring during storage (Lurie 1999).

Diseases

In trials on wounded fruit with extracts obtained from wild edible herbaceous species, *Sanguisorba minor* extract completely inhibited brown rot (*Monilinia laxa*) on nectarines (Gatto *et al.* 2012). Fruit were wounded, covered with carnauba wax and then inoculated or fruit were wounded, inoculated and then covered with carnauba wax. There was no mycelial growth of *M. fructicola* at any of the wax concentrations (1, 2, 3 and 4.5%). *Rhizopus stolonifer* was completely inhibited by carnauba wax

at all concentrations except at 1%. There was 50% inhibition of spore germination for *M. fructicola* and 90% for *R. stolonifer* on the surface of nectarines covered with 9% carnauba wax. Protective application of 4.5 and 9% carnauba wax significantly reduced incidence, but they concluded that control of both diseases by the application of carnauba wax was inefficient (Gonçalves *et al.* 2010). Brown rot was effectively controlled by exposing fruit to 50°C and 95–99% r.h. for 2 h. However, it did not provide protection for further *M. fructicola* infections, indicating that fruit was susceptible to subsequent infections after the treatment process and before cool storage. One percentage chitosan applied at 20°C had a preventive effect against further *M. fructicola* infections on heat-treated fruit that had been previously inoculated: brown rot incidence was reduced to 10%, in comparison with the control (73%). However, chitosan applied to wounded fruit had a poor preventive effect (Casals *et al.* 2012). Casals *et al.* (2010b) reported that a postharvest curing at 50°C and 95–99% r.h. for 2 h satisfactorily controlled brown rot on several nectarine cultivars. Different maturity levels affected curing efficacy. As fruit maturity increased, the efficacy of a postharvest curing treatment decreased from 95% control of brown rot (harvest mature fruit) to 65% (the most advanced mature fruit). The effect of *M. fructicola* infection time prior to treatment also affected the curing efficacy. When the infection time was increased from 0 to 48 h, brown rot control decreased from 90% to 64%. When fruit with natural inoculum was surface sterilized prior to the curing, complete brown rot control resulted.

Noni

Rubiaceae

Morinda citrifolia L. Other common names include apatot, beach mulberry, cheese fruit, dog dumpling, great morinda, Indian mulberry, kumudu, mengkudu and pace. Its native range is Southeast Asia and Australasia and it is now widely naturalized and cultivated throughout the tropics (Nelson 2001). It is used traditionally for medicinal purposes and fruit and juice extracts are reportedly therapeutic for diabetes, high blood pressure and certain types of cancer. Its seeds, leaves, bark and roots as well as the

fruit have been used medicinally by the Polynesians for more than 2000 years (Dixon *et al.* 1999). It is currently a popular medicinal plants in Hawai'i and important in traditional culture (Nelson 2001). Both the fruit and damnacanthol, an anthraquinone compound extracted from noni roots, were studied for anti-cancer properties (Chan-Blanco *et al.* 2006). Hepatitis had been associated with drinking noni juice but West *et al.* (2009) corroborated previous conclusions that consumption of noni fruit juice is unlikely to induce adverse liver effects. It can grow up to 9 m tall. The fruit is a multiple fruit that contains many seeds and is oval in shape and up to 18 cm long. The skin is green as it grows and turns yellow then almost white as it ripens. The fruit has a pungent odour when ripening and a bitter taste but is eaten either raw or cooked as a famine food or even a staple food in some areas (Dixon *et al.* 1999, Nishijima and Wall 2011). Ripening noni fruit had a non-climacteric respiratory pattern with an average rate of 34 mg CO₂ kg⁻¹ h⁻¹ at 22 °C and no detectable ethylene production (Nishijima and Wall 2011).

Ōhelo berry

Ericaceae

Vaccinium reticulatum. In 'Hawai'ian Mythology', Martha Beckwith writes of the legend of Kaohelo, who instructs her son Kiha to bury her, when she dies, 'on the navel of your grandmother at Kilauea'. Out of her flesh springs the creeping ōhelo, out of her bones the ōhelo bush, other parts of her body are thrown to Maui, O'ahu, Kaua'i and become ōhelo bushes on those islands. Ōhelo berries were a symbolic focal point in the evolution of Hawai'ian traditional beliefs. In 1824, the high chiefess Kapi'olani, a devout Christian, performed a defiant act against Pele in hopes of demonstrating to her people the foundation of her new faith and to win converts. Ignoring dire warnings, Kapi'olani descended towards the fiery pit of Halema'uma'u and read passages from the Bible and ate ōhelo berries without Pele's permission (Wagner *et al.* 1990).

It is a small evergreen shrub from about 15 to about 130 cm high, rarely up to 2 m. The leaves are leathery, oval, 1–3 cm long, red when freshly emerging, then green or green with reddish patches. Often the topmost leaves of the main stem will have

Table 145 The composition of ōhelo berries for 100 g⁻¹ fresh weight. (source: adapted from USDA 2012)

Water	92.30 g	Potassium	38 mg
Energy	28 kcal	Sodium	1 mg
Protein	0.38 g	Total ascorbic acid	6.0 mg
Total lipid (fat)	0.22 g	Thiamine	0.017 mg
Carbohydrate, by difference	6.84 g	Riboflavin	0.036 mg
Calcium	7 mg	Niacin	0.270 mg
Iron	0.09 mg	Vitamin B-12	0.00 µg
Magnesium	6 mg	Vitamin A	42 µg RAE
Phosphorus	10 mg	Vitamin A	830 IU

adult foliage while the rest of the plant will still have juvenile foliage. The flowers are bell-shaped, 8–12 mm long and red to yellow or pink in colour. The fruit is an edible 8–14 mm in diameter, ranging in colour from blue to purple to red to orange to yellow. The colour does not necessarily indicate the ripeness of the berries. The berries taste similar to cranberry, less ripe ones being tart, while ripe berries are quite sweet (Wagner *et al.* 1990). The chemical content was given by USDA (2012) in Table 145.

Olives

Oleaceae

Olea europaea L., *O. europaea* subsp. *europaea* L. They originated in the Mediterranean region and have been a source of food, medicine and oil since ancient times. It is now grown throughout the world in sub-tropical and warm-temperate regions. It is a small slow growing tree whose fruit is a small green drupe that may turn dark blue or purplish as it matures has a single hard seed. The tree produces its flowers and fruits on wood of the previous year. Total world production in 2010 was estimated by FAO (2013) as 20,818,612 tonnes.

Harvesting and grading

Harvest maturity is based on fruit size and skin colour. The oil content, which increases throughout maturation, can be used as an indicator by analysing samples and when the level is high enough all the fruit from that orchard are harvested. To grade fruit into different maturities, specific gravity

Table 146 Respiration rate of olives at different temperatures (source: adapted from Crisosto and Kader 2002d)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
5	10–20
7.5	16–24
10	24–32
20	40–80

can be used by floating the fruit in a brine solution of the appropriate salt concentration (Hulme 1971). Magnetic resonance imaging has been used to obtain images of defective pits in olives (Chen *et al.* 1989).

Postharvest physiology

They are classified as non-climacteric. Crisosto and Kader (2002d) reported that green olives produce less than 0.1 µl kg⁻¹ h⁻¹ and black olives 0.5 µl kg⁻¹ h⁻¹ ethylene at 20 °C but they are moderately sensitive to ethylene greater than 1 µl L⁻¹, which can cause a loss of green color and flesh firmness. SPLFS (2001) reported that they had low (4–40 nM kg⁻¹ h⁻¹) ethylene production at 20 °C and moderately sensitive to ethylene. They also gave their respiration rate as 65–116 W tonne⁻¹ at 15 °C, 114–146 W tonne⁻¹ at 20 °C and 121–181 W tonne⁻¹ at 25 °C (11–19 ml CO₂ kg⁻¹ h⁻¹ at 15 °C, 19–24 ml CO₂ kg⁻¹ h⁻¹ at 20 °C and 20–30 ml CO₂ kg⁻¹ h⁻¹ at 25 °C). Crisosto and Kader (2002d) gave their respiration rate in Table 146.

Storage

Storage below 7.2 °C resulted in the flesh turning brown at the stem end. Unusually, ripe fruit were more susceptible to chilling injury than less ripe fruit and it could occur even at 10 °C within a month (Lutz and Hardenburg 1968). The fruit will freeze at about –2.4 to –1.4 °C (Wright 1942) or –1.4 °C (SPLFS 2001). Crisosto and Kader (2002c) reported that freshly harvested olives are affected with chilling injury at less than 5 °C. However, refrigerated storage recommendations include

- 5–10 °C and 85–90% r.h. for 4–6 weeks (Hardenburg *et al.* 1990);

- 7.2 °C and 85–90% r.h. for 28–42 days (SeaLand 1991);
- 5–10 °C and 85–90% r.h. for 28–42 days (SPLFS 2001);
- 5–7.5 °C with 90–95% r.h. (Crisosto and Kader 2002d).

Controlled atmosphere storage

Recommended storage conditions were 8–10 °C with 5–10% CO₂ and 2–5% O₂ that had a fair effect, but was not being used commercially (Kader 1985). Subsequently Kader (1989, 1992) recommended 5–10 °C with 0–1% CO₂ and 2–3% O₂. SPLFS (2001) recommended 5–10 °C with 2–3% O₂ + 0–1% CO₂ which had fair effect and extended postharvest life by 21 days compared to refrigerated storage in air. Kader (1989) found that green Manzanillo olives were damaged when exposed to CO₂ levels of 5% and above, but storage was extended in 2% O₂. They also found that in air their storage life was 8 weeks at 5 °C, 6 weeks at 7.5 °C and 4 weeks at 10 °C, but in 2% O₂ the storage life was extended to 12 weeks at 5 °C and 9 weeks at 7.5 °C. Crisosto and Kader (2002d) reported that storage of fresh green olives in 2–3% O₂ + 0–1% CO₂ resulted in delayed senescence and softening for up to 12 weeks at 5 °C and 9 weeks at 7.5 °C. They found that storage in less than 2% O₂ could cause off-flavours. Levels of greater than 5% CO₂ may increase severity of chilling injury if olives are stored below 7.5 °C. They also found that fresh black olives should be processed as soon after harvest as possible, but they can be stored at 5 °C in 2% O₂ for up to 4 weeks.

Orange

Rutaceae

Citrus sinensis (L.) Osbeck. The various species of the genus *Citrus* are all believed to be native to the subtropical and tropical regions of Asia and the Malaysian Archipelago. *C. sinensis* is probably native to Cochin, China. Cultivation of oranges has spread throughout tropical and subtropical regions and they were introduced into Europe in the second half of the 15th century. Columbus took orange seeds to Haiti in his second voyage in 1493 from where they have spread throughout the Caribbean islands and to mainland America (Purseglove 1975). It is now

the most important and widely grown *Citrus* species. Oranges grown in the tropics tend to have a higher sugar and total solids content than those grown in the sub-tropics. However, tropical grown oranges tend to be less orange in colour and peel less easily. These latter two factors seem to be related more to the lower diurnal temperature variation that occurs in the tropics rather than the actual temperature difference between the tropics and subtropics. The fruit are borne on trees that grow up to 12 m high. Trees produce axillary flowers that are white and have a characteristic and beautiful scent. The fruit is a berry or hesperidium. It will freeze at about -2.3 to -2.0°C (Wright 1942). The chemical content was given by USDA (2012) in Table 147. Total world production in 2010 was estimated by FAO (2013) as 68,332,573 tonnes.

Harvesting

Being non-climacteric the fruit does not ripen after harvest and must therefore be picked at peak maturity. A visual method is to observe the size, smoothness and change in colour of the fruit from green to orange. The juice content increases as they mature on the tree. By taking representative samples of the fruit, extracting the juice in a standard and specified way and then relating the juice volume to the original mass of the fruit it is possible to specify its maturity. In the United States the minimum juice volume for navel oranges was 30% and for other oranges 35%. Light transmission properties of fruit can be used to measure their maturity. With this method it was possible to grade fruits, which were indistinguishable by visual examination. A photoelectric machine was used for colour sorting citrus fruit. The ratio between TSS and

Table 147 The composition of orange fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	All commercial varieties	California Valencia	Navel	Florida
Water (g)	86.75	86.34	85.97	87.14
Energy (kcal)	47	49	49	46
Protein (g)	0.94	1.04	0.91	0.70
Total lipid (fat) (g)	0.12	0.30	0.15	0.21
Carbohydrate, by difference (g)	11.75	11.89	12.54	11.54
Total dietary fibre (g)	2.4	2.5	2.2	2.4
Total sugars (g)	9.35	—	8.50	9.14
Calcium (mg)	40	40	43	43
Iron (mg)	0.10	0.09	0.13	0.09
Magnesium (mg)	10	10	11	10
Phosphorus (mg)	14	17	23	12
Potassium (mg)	181	179	166	169
Sodium (mg)	0	0	1	0
Zinc (mg)	0.07	0.06	0.08	0.08
Total ascorbic acid (mg)	53.2	48.5	59.1	45.0
Thiamine (mg)	0.087	0.087	0.068	0.100
Riboflavin (mg)	0.040	0.040	0.051	0.040
Niacin (mg)	0.282	0.274	0.425	0.400
Vitamin B-6 (mg)	0.060	0.063	0.079	0.051
Folate (μg DFE)	30	39	34	17
Vitamin B-12 (μg)	0.00	0.00	0.00	0.00
Vitamin A (μg RAE)	11	12	12	11
Vitamin A (IU)	225	230	247	225
Vitamin E (α -tocopherol) (mg)	0.18	—	0.15	0.18
Vitamin D (D2 + D3) (μg)	0.0	0.0	0.0	0.0
Vitamin D (IU)	0	0	0	0
Vitamin K (phylloquinone) (μg)	0.0	—	0.0	0.0
Fatty acids, total saturated (g)	0.015	0.035	0.017	0.025
Fatty acids, total monounsaturated (g)	0.023	0.055	0.030	0.039
Fatty acids, total polyunsaturated (g)	0.025	0.060	0.031	0.042

TA can also be used with ranges between 7 : 1 and 9 : 1 for full maturity (Jahn and Gaffney 1972). The maturity standards for California navel oranges require a ratio of TSS : TA of 8 : 1 and yellow-orange peel colour on at least 25% of the surface for a minimum of 90% of the lot (California Department of Food and Agriculture 2003). Obenland *et al.* (2009) found that the TSS : TA ratio was not as closely related to the likeability assessment called BrimA. BrimA was calculated by subtracting TA from TSS after multiplying TA by a constant that differed by fruit type. At the minimum maturity standard of 8 : 1, the hedonic score calculated from the overall regression equation was 4.4, a value well into the dislike range, indicating that the current standard is likely set at too low of a value to satisfy most consumers.

Harvesting methods

Oranges harvested for juice extraction may be removed from the trees by powerful wind machines being dragged through the orchard followed by a device for collecting them from the ground. The grass beneath the trees is usually mown before harvesting and these collecting devices usually have nylon brushes that sweep up the fruit and transfer them to containers. Tree shakers can also be used. If oranges are too turgid at harvest the oil glands in the skin can be ruptured releasing phenolic compounds and causing damage to the peel resulting in oleocellosis (Wardlaw 1937). In some cases fruit were kept in the basket in which they were harvested for a couple of hours before being transported to the packhouse. This allowed the fruit to lose a little moisture a practice that is called quailing.

Grading

X-rays can also be used to detect internal disorders of crops including granulation in oranges (Johnson 1985). Clarke (1996) described a machine where there are two cables along which the crop runs are made up from high tensile, polyethylene-coated steel. When the crop reaches the prescribed point, ejector bars controlled by solenoid valves and operated by compressed air cylinders, push it into the chute. The machine is very gentle to the crop and high drops are unnecessary although padded chutes can be provided.

Waxing and washing

All citrus fruits can benefit from the application of waxes and subsequent polishing. This is not simply to enhance the appearance, which of course is important, but also to improve the storage quality of the product. When the crop is in the field or even during harvesting, transport, washing or grading it can undergo some scratching or abrasion that not only removes the natural layer of wax but also scars the protective layer of skin around the fruit. Washing in particular is essential in the removal of bird droppings, insect marks, chemical residues and general field dirt but can remove much of the natural wax layer especially if washing is with detergents. The natural layer of wax reduces moisture loss from the fruit. Citrus fruits may be improved in appearance by synthetic wax application and some producers may add colouring dyes to the wax in order to modify the colour in addition to providing an enhanced shine. Natural waxes are preferred such as sugar cane wax, carnauba wax, shellac and various resins. These may be applied to the fruit in foam, in a liquid bath, a liquid spray or by sponge or brush rollers. Their use application rates may be governed by legislation in the country where the coating is being applied or in the country where the fruit are to be exported. It is essential that these regulations as well as the manufacturer's recommendations be strictly adhered to. Mechanized spray systems often apply an excess of fluid so the unused surplus flows through the conveyor back into the holding vessel ready for reapplication. The fruit must be dried after waxing to give good adhesion and retention of the wax. Drying is usually done in a drying tunnel and may also incorporate soft brushes. A blast of warm air is often directed at the fruit as it passes along the conveyor under the fan or else the heaters are under the fruit and the fan draws the air through it by suction (Clarke 1996). Storage experiments using organically grown Shamouti showed that hot water brushing at 56 °C for 20 s reduced decay development by 45–55% and did not cause surface damage or influence fruit weight loss or internal quality parameters (Porat *et al.* 2000). Kouassi *et al.* (2012) reported excellent disease control when *Cinnamomum zeylanicum* essential oils were incorporated in shellac and/or carnauba wax compared with when the essential oils were incorporated into paraffin or polyethylene wax formulations. Disease control by essential oils/waxes appeared to depend on the

volume that remained on the fruit skin and probably on the retention of essential oils components.

Curing

Tariq (1999) showed that placing fruits in sealed polyethylene film bags and exposing them to temperatures in the range 25–35 °C for between 3 and 48 h (the lower the temperature the longer the exposure time required) completely eliminated the browning and fungal growth on damaged fruits.

Postharvest physiology

It is a non-climacteric fruit and their respiration rate increased rapidly with increasing temperature as would be expected (Table 148). Carmona *et al.* (2012) found that carotenoid biosynthesis was stimulated during storage of the cultivar Navelina at 12 °C and 90–95% r.h. for 7 weeks. This resulted in improved peel and pulp colouration and also pro-vitamin A activity of the flesh was increased.

Chilling injury

Chilling injury symptoms begin as light brown discoloration surrounding the oil vesicles on the skin with a number of small irregular spots appearing at the same time, either localized or scattered over the surface. They increase in size, coalesce and the tissue in between the oil vesicles is depressed so that the vesicles themselves are prominent giving a pinhead effect. The vesicle outlines usually appear darker than the centre. They continue to turn a darker brown and this may be accelerated when they are transferred to higher temperatures. The oil vesicles then collapse as the tissue dries out giving minute cavities. During prolonged storage that may encroach into the white albedo beneath, but this varies with cultivar. Eventually the fruit suffer from watery breakdown (Wardlaw 1937). Hardenburg *et al.* (1990) showed that storage of Valencia, grown in Florida, at 1 °C in

0 or 5% CO₂ and 15% O₂ followed by 1 week in air at 21 °C had less skin pitting after 12 weeks compared to those stored in air.

Storage

Valencia oranges from Florida and the cultivar Pineapple can be stored for 15–20 weeks at 3 °C and have a marketable life of 3–7 days after removal from storage. Temperatures of 0 °C or less resulted in pitting and temperatures above 4 °C led to excessive decay. The later into the season the fruit is harvested the shorter the storage life. Early season cultivars (Pineapple and Hamlin) are more susceptible to chilling injury than fruits harvested later in the season (Valencia). An imbalance between CO₂ and O₂ in the fruit store may cause them to develop off flavours. Having good ventilation around the fruit can prevent this (Davies and Albrigo 1994). General refrigerated storage recommendations include

- 7.2 °C (Trinidad) (Wardlaw 1937);
- 4.5 °C (storage and shipment from South Africa) (Fidler 1963);
- 0–4 °C and 85–90% r.h. for 1–4 months (Anonymous 1967);
- 0–4 °C and 85–90% r.h. (Spain) (Anonymous 1967);
- 4–6 °C and 85–90% r.h. for up to 6 months (Israel) (Anonymous 1967);
- 5.6–7.2 °C and 85–90% r.h. for 18 weeks (India) (Anonymous 1967);
- 7.2 °C and 85–90% r.h. for 21–56 days (California, Arizona) (SeaLand 1991);
- 2.2 °C and 85–90% r.h. for 56–84 days (Florida, Texas) (SeaLand 1991);
- 0–4 °C for 2 months or more (Davies and Albrigo 1994).

Specific storage recommendations for different cultivars and production areas include

Blood Orange

- 4.4 °C and 90–95% r.h. for 21–56 days (SeaLand 1991).

Camargo

- 2 °C and 90% r.h. for 3 months from Brazil (Snowdon 1990);

Table 148 Effects of temperature (°C) on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of oranges grown in Florida (source: adapted from Haller *et al.* 1945)

Temperature (°C)	0	4.4	10	15.5	21.1	26.6	32.2	37.7
Respiration	3.1	6.4	12.3	20.7	29.9	35.4	46.5	69.1

- 4 °C and 90% r.h. for 2–3 months from South Africa (Snowdon 1990).

Castellana

- 1–2 °C and 90% r.h. for 2–3 months from Spain (Snowdon 1990).

Jaffa

- 8 °C and 90% r.h. for 3 months from Israel (Snowdon 1990);
- 7.8 °C and 85–90% r.h. for 56–84 days (SeaLand 1991).

Moroccan

- 2–3 °C and 90% r.h. 2–3 months from Spain (Snowdon 1990).

Navel

- Navel oranges from California were sometimes stored from 2 to 6 weeks at 3–4 °C during winter and spring in order to even out the supply (Stahl and Camp 1963);
- 3 °C and 85–90% r.h. for 8–10 weeks from Spain (Mercantilia 1989);
- 2–7 °C and 85–90% r.h. for 5–8 weeks from California (Mercantilia 1989);
- 4.5–5.5 °C and 90% r.h. 1–2 months from Australia (Snowdon 1990).

Ponkan

- 4.4 °C and 85–90% r.h. for 3–4 weeks with 7.5% loss (Pantastico 1975).

Salustiana

- 2 °C and 90% r.h. for 3–4 months from Spain (Snowdon 1990).

Sathgudi

- 5.6–7.2 °C and 85–90% r.h. for 16 weeks with 15% loss (Pantastico 1975).

Shamouti

- 4–5 °C and 85–90% r.h. for 6–8 weeks from Israel (Mercantilia 1989);
- A combination of preharvest potassium spray with storage at 5 °C gave good control of superficial rind pitting (Tamim *et al.* 2000).

Swikom

- 8.9–10 °C and 85–90% r.h. for 4–5 weeks with 8% loss (Pantastico 1975).

Valencia

- 0 °C and 85–90% r.h. for 8–12 weeks for fruit grown in Florida or Texas (Lutz and Hardenburg 1968);
- 4.4–6.7 °C and 85–90% r.h. for fruit grown in California (Lutz and Hardenburg 1968);
- 8.9 °C from Arizona harvested in March or 3.3 °C from Arizona harvested in June (Lutz and Hardenburg 1968);
- 4.4–6.1 °C and 88–92% r.h. for 5–6 weeks with 12% loss (Pantastico 1975);
- 0–1 °C and 85–90% r.h. for 8–12 weeks from Florida (Mercantilia 1989);
- 2–7 °C and 90% r.h. for 1–2 months from California (Snowdon 1990);
- 2–3 °C and 90% r.h. for 2–3 months from Cyprus (Snowdon 1990);
- 0–1 °C and 90% r.h. for 2–3 months from Florida or Texas (Snowdon 1990);
- 2 °C and 90% r.h. for 2–3 months from Israel (Snowdon 1990);
- 2–3 °C and 90% r.h. for 2 months from Morocco (Snowdon 1990);
- 4.5 °C and 90% r.h. for 2–4 months from South Africa (Snowdon 1990);
- 2 °C and 90% r.h. for 3–4 months from Spain (Snowdon 1990).

Verna

- 1–2 °C and 90% r.h. for 3–4 months from Spain (Snowdon 1990).

Washington Navel

- 2–7 °C and 90% r.h. for 1–2 months from the United States (Snowdon 1990).

Controlled atmosphere storage

Anonymous (1968) claimed that CA storage could have deleterious effects on fruit quality, particularly through increased rind injury and decay or on fruit flavour. In contrast Hardenburg *et al.* (1990) showed that Valencia grown in Florida retained better flavour during storage for 12 weeks at 1 °C in 0 or 5% CO₂ and 15% O₂ followed by 1 week in air at 21 °C than those stored in air, but CO₂ levels of 2.5–5% especially when combined with 5 or 10% O₂ adversely affected flavour retention. Other recommendations include

- 5–10 °C with 5% CO₂ and 10% O₂ had fair effect on storage but was not being used commercially (Kader 1985);
- 5–10 °C with 0–5% CO₂ and 5–10% O₂ (Kader 1989, 1992);
- 7.2 °C with 5% CO₂ and 10% O₂ (SeaLand 1991);
- 1–9 °C and 85–90% r.h. with 5–10% O₂ and 0–10% CO₂ for 3–12 weeks (Burden 1997).

Hypobaric storage

The cultivar Fukuhara showed lower rates of ethylene production and respiration rate after low-pressure storage than fruits kept at atmospheric pressure. Oranges stored at 190 mm Hg and 98% r.h. decayed more rapidly after return to atmospheric pressure than fruits stored at 190 mm Hg and 75% r.h. or atmospheric pressure and 86% r.h. (Kim and Oogaki 1986). This recommendation is surprising since the fruits stored at these humidities and low pressure would have been severely desiccated.

Degreening

Oranges are often degreened after harvest by exposing them to ethylene gas, but brown spotting on the skin may be due to excessive ethylene concentration during degreening. Concentrations in excess of 200 µl L⁻¹ or too high a temperature can give this effect (Wardlaw 1937). Degreening temperatures range between 25 and 29 °C and humidity as high as possible, generally between 90 and 95% r.h. with ethylene at between 1 and 10 µl L⁻¹ for 24–72 h. Ladaniya and Singh (2001) found that respiration rate increased from initial 35 up to 80 mg CO₂ kg⁻¹ h⁻¹ in ethylene exposed fruits and slowly declined after removal from the ethylene atmosphere. Fruit firmness, juice content and TSS and ascorbic acid remained unchanged with ethylene treatment but TA declined and decay losses due to *Geotrichum candidum* were lower in degreened fruits. The actual choice of conditions will vary between different situations, particularly whether they have been grown in the tropics or subtropics. The cultivar and the stage of maturity at harvest should also be taken into account. Application of ethylene may be by an initial injection of the correct level or by continuously trickling

it into the room. Other conditions for degreening include

- 27 °C and 85–92% r.h. with ethylene gas trickled into the room to achieve 20–30 µl L⁻¹ for 24–48 h (Winston 1955).
- 20–25 °C and 90% r.h. with 5–10 µl L⁻¹ of ethylene at or up to 72 h with air circulation of one room volume per minute and 1–2 fresh air changes per hour in California (Eaks 1977).
- 27.5–29.5 °C and 90–95% r.h. with 1–5 µl L⁻¹ ethylene at or up to 72 h with good air circulation and 1 fresh air change per hour in Florida (McCorrack and Wardowski 1977).
- 27–29 °C and 90–95% r.h. with 5–10 µl L⁻¹ ethylene for 48 h with four air changes per hour and air circulation of 0.5–0.6 L s⁻¹ kg⁻¹ of fruit for the cultivar Mosambi in India (Ladaniya and Singh 2001).

Degreening can have effects on other constituents other than chlorophyll. Sdiri *et al.* (2012) found that with Navelina oranges exposure to 2000 µl L⁻¹ ethylene for 120 h at 21 °C and 95% r.h. and then 1 °C for 16 days as a quarantine treatment plus 7 days at 20 °C and 95% r.h. for shelf life did not induce detrimental changes in anti-oxidant capacities, ascorbic acid or total phenolic content. Although some changes were observed in individual flavonoid compounds, these did not contribute to a loss in the total content of flavanones and flavones after ethylene degreening and the subsequent quarantine treatment. Mayuoni *et al.* (2012) found that ethylene degreening had no effect on juice, TSS and acid contents and had only minor effects on contents and composition of juice aroma volatiles in the cultivar Navel. Also sensory analysis tests revealed that ethylene degreening did not affect their flavour.

Diseases

Several diseases develop postharvest on fruit (Snowdon 1990). Pérez *et al.* (2012) reported that the extensive use of imazalil in Uruguayan citrus packhouses to control *Penicillium* spp. favoured the selection and proliferation of resistant isolates and a survey of *P. digitatum* isolates indicated imazalil-resistant isolates occurred in packhouses and not in citrus groves. Commercial applications

were 3.0 g L^{-1} imazalil and resistant isolates were able to grow in fruit with imazalil residues of 0.92 and 3.08 mg kg^{-1} . They concluded that imazalil at 3.0 g L^{-1} effectively controlled *P. digitatum* but not resistant ones. In Argentina Sayago *et al.* (2012) reported that the main constraint on the citrus industry was the management of postharvest diseases, mostly of fungal origin with *Penicillium digitatum* and *Geotrichum citri-aurantii*, two very important fungal species causing citrus postharvest disease. In Florida, orange trees that were sprayed with $300\text{--}500 \mu\text{L L}^{-1}$ benomyl more than a month before harvest had less postharvest disease (*Penicillium* spp. and stem end rots) than unsprayed trees (Brown and Albrigo 1972). However, benomyl is not permitted in some countries. Exposing oranges to 30°C and 90–100% r.h. for several days after harvest was shown to reduce decay associated with *Penicillium* spp. infection (Hopkins and Cubbage 1948). Fumigating oranges with 2-AB was also recommended for postharvest disease control (Eckert 1969). With the restrictions on the postharvest use of chemicals other methods of disease control are being used. Population of *Paenibacillus polymyxa*, a bacterial strain isolated as an endophyte from the root tissue of *Sophora tonkinensis*, increased rapidly in citrus fruit wounds when inoculated at 25°C but remained static at 6°C . *P. polymyxa* also significantly reduced the natural development of *P. digitatum* following storage at 25°C for 4 weeks or at 6°C for 4 weeks followed by 25°C for 2 weeks. It did not affect weight loss, firmness, TSS, ascorbic acid and TA of the treated fruit (Lai *et al.* 2012). Youssef *et al.* (2012b) reported that aqueous salt solutions applied at 2%, w/v by spraying before harvest or dipping after harvest. The fruit were then stored at $4 \pm 1^\circ\text{C}$ and 95–98% r.h. followed by 7 days of shelf life at $20 \pm 2^\circ\text{C}$. Preharvest application of sodium carbonate, potassium carbonate or sodium silicate completely inhibited the incidence of decay as compared to the water control. When salts were applied after harvest, the activity was in general less pronounced with sodium carbonate and potassium carbonate being the most effective. In *in vivo* tests Sayago *et al.* (2012) showed that aqueous formulation of the native plant *Parastrephia lepidophylla* at 600 mg L^{-1} had curative and

protective effects on the fruit against infection by a wild strain of *P. digitatum*. Youssef *et al.* (2012a) reported that most decay was caused by *P. digitatum* and *P. italicum* with an average incidence of 5% for both the cultivars Tarocco and Valencia late during storage at 4°C for 1 month followed by 1 week of shelf life at $20 \pm 2^\circ\text{C}$. Decay caused by *Botrytis cinerea* and *Alternaria* spp. was also observed. Those treated with imazalil had less than 1% postharvest rots.

In South Africa, Erasmus *et al.* (2012) reported that the maximum residue limit for imazalil on citrus fruit was $5 \mu\text{g g}^{-1}$, whereas $2\text{--}3 \mu\text{g g}^{-1}$ was a biologically effective residue level that should at least inhibit green mould sporulation. Standard compliance auditing of residue levels of citrus fruit, however, indicates that fruit from the majority of packhouses have residues of $\approx 1 \mu\text{g g}^{-1}$. They did a packhouse survey, which showed that the majority of packhouses applied imazalil in a sulphate salt formulation through a fungicide dip tank giving residue of $\approx 1 \mu\text{g g}^{-1}$ that had excellent curative and protective activity against *P. digitatum* isolates sensitive to imazalil. However, curative control of imazalil-resistant isolates was substantially reduced and protective control was lost, even at twice the recommended concentration, or was sporulation inhibited. The use of 2% sodium bicarbonate buffered imazalil sulphate solutions at $\text{pH} \pm 8$, compared with $\text{pH} \pm 3$ of the unbuffered solutions, markedly increased imazalil residue loading on Navel and Valencia oranges and improved curative and protective control of imazalil-resistant isolates although the MRL was exceeded after 45 s exposure in pH 8 solutions.

In trials performed on wounded fruit with extracts obtained from wild edible herbaceous species, *Orobancha crenata* extract strongly reduced green mould on oranges (Gatto *et al.* 2012). Montesinos-Herrero *et al.* (2011) reported that green mould and blue mould were effectively controlled by fumigation for 6 h at 22°C with two applied dosages of $3000 \mu\text{L L}^{-1}$ of ammonia that was injected initially and again 2 h later. This treatment did not injure the oranges. However, about 30% of the conidia of *P. digitatum* and 10% of those of *P. italicum* could germinate after a 6-h fumigation where two injections of $6000 \mu\text{L L}^{-1}$ of ammonia were

applied. Ammonia fumigation controlled an isolate of *P. digitatum* that had a high level of resistance to imazalil. When fruit were first immersed in 10 or 30 mg L⁻¹ imazalil (about 10% of typical commercial rates) before ammonia fumigation, a single fumigation with 1500 µl L⁻¹ of ammonia was adequate to control both green mould and blue mould and the increase in effectiveness was usually additive and sometimes synergistic. The authors discussed the practical application in commercial practice and concluded that ammonia fumigation on their arrival to packinghouses may be a feasible practice, since it could employ the existent ethylene degreening chambers. Ammonia could replace synthetic fungicides or augment imazalil.

Physiological disorders

There are many physiological disorders of citrus fruits that were reviewed by Snowdon (1990). Oleocellosis is a browning and pitting of the skin. It is due to the oil vesicles being ruptured, which release phenolic compounds that damage the cells of the skin. The actual damage is the tissue drying out and giving minuscule cavities and during prolonged storage it may encroach on the albedo beneath (Wardlaw 1937). Desiccation consists of wrinkled and brown areas of peel spreading as it develops more frequently at the stem end (Wardlaw 1937). Superficial rind pitting of Shamouti orange causes losses to growers. Some symptoms could be seen on the tree or in the packhouse, the majority only showed symptoms 3–5 weeks after harvest, during shipment and marketing. Ethylene increased the incidence of superficial rind pitting but storage at 5 °C restricted its development (Tamim *et al.* 2000).

Pests

Oranges are attacked by fruit flies whose control can be a quarantine requirement in some importing countries. For example the Japanese Government require cold treatment for oranges from Israel (0.6 °C for 14 days), South Africa and Swaziland (−0.6 °C for 12 days) against Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) and Oriental fruit fly (*Bactrocera dorsalis* Hendel) from Taiwan (Kitagawa 1993). Sdiri *et al.* (2012) used exposure to 1 °C for 16 days as a quarantine treatment against *C. capitata* in Navelina oranges.

Otahiete apple

Annacardiaceae

Spondias cytherea Sonnerat synonymous with *S. dulcis* Forst. f. Other common names include ambarella, caja-umbu, golden apple, imbu and umbu. Its origin was reported to be unknown by Bicas *et al.* (2011) or a native of Polynesia by Mohammed *et al.* (2011). Purselove (1975) reported that the origin of *S. cytherea* was Polynesia and Kennard and Winters (1960) reported that the closely related species, *S. tuberosa*, was from Brazil. Bicas *et al.* (2011) reported that it has been considered a natural hybrid between *S. mombin* L. and *S. tuberosa* Arruda Câmara. It is widely distributed in some northeastern Brazilian states.

It is an erect, semi-deciduous tree growing up to 18 m high. Kennard and Winters (1960) reported that it produces small white flowers in terminal panicles and the fruit are globular to ovoid, up to about 7 cm long with a tough skin that is yellow when ripe with a refreshing aroma and sour flavour and they reported that *S. tuberosa* to be the best flavoured of the *Spondias* spp. They found that some varieties, however, produce resinous disagreeably flavoured fruit. Mohammed *et al.* (2011) quoted sizes of fruit varying up to 224 g but in Granada and St Vincent fruit of 450 g have been observed.

Kennard and Winters (1960) stated that the fruit was a fair source of vitamin C and a good source of iron. Narain *et al.* (2007) identified the volatile compounds present in the pulp of fruits of caja-umbu (*Spondias* sp.) harvested at either half-ripe or ripe maturity and found 67 volatiles in half-ripe fruit. The main components were identified as β-caryophyllene (22.2%), 2-methyl butanal (19.3%), 2-hexanol (18.6%), ethyl butyrate (7.6%) and α-caryophyllene (3.9%). In the ripe fruit, 70 compounds were identified that were 2-methyl butanal (28.4%), 2-hexanol (15.0%), β-caryophyllene (14.1%), ethyl butyrate (6.1%) and α-caryophyllene (2.4%). β-caryophyllene and 2-hexanol which were quantitatively higher in half-ripe fruits, while 2-methyl butanal, known to present pungent fresh fruit aroma, increased as the fruit matured. Galvão *et al.* (2010) detected a total of 148 compounds in half-ripe fruit and 159 in ripe fruit pulp of umbu (*S. tuberosa*). The principal compounds identified in the ripe fruit pulp were limonene, 1-heptanol, 2-pentanol, 3-hexanol,

1-nonanol, 2-octanol, 2-nonanol, 2,2-dimethyl 4-octenal, 3-methyl ethyl 2-butanoate, butyl benzoate, 3-allyl cyclohexene, 2-acetyl furan, 1-penten-3-one, 3-hexanone, 5-methyl furfural, 2-hexyl furan, β -caryophyllene and methyl-pyrazine.

Harvesting

Harvest maturity is based on changes of skin colour from deep green to pale glossy green. For miniature golden apples they received acceptable ratings when harvested 19–23 weeks after fruit set (Mohammed *et al.* 2011).

Postharvest physiology

Mohammed *et al.* (2011) reported that they were climacteric fruit with the initiation of the climacteric rise occurring at colour break, 21–23 weeks after fruit set for miniature golden apples. No ethylene production was detected up to colour break from green to yellow, but when they were harvested their respiration rate increased, ethylene production began and they ripened rapidly within 2–5 days.

Storage

Mohammed and Wickham (1997) found that fruit stored at 5 °C for 7 days showed symptoms of chilling injury as tiny scattered pits. The severity of the symptoms increased with time with the pits coalescing into larger depressed areas that were discoloured to a dark brown colour. They referred to that symptom as *sheet pitting*. Even exposure to 5 °C for as little as 3 days resulted in the development of chilling injury symptoms when the fruit were removed to 30 °C. They also found some reduction in chilling injury when fruits had been waxed before storage and to a lesser extent if they were sealed in LDPE film bags. The latter treatment resulted in some bacterial soft rot caused by *Erwinia* sp. Daulmerie (1994, quoted by Mohammed *et al.* 2011) recommended storage at 10–12 or 13 °C with 90–95% r.h. for up to 2 weeks or 11 °C for 'sanitized' fruit for up to 25 days with an ethylene absorber.

Ripening

Recommended ripening conditions were 2–4 days at ambient conditions or 20–22 °C and 90–95% r.h.

with 500 ppm Ethrel for 1–1½ days followed by 7–8 °C and 90–95% since fully ripe fruit were found to be less sensitive to chilling injury (Mohammed *et al.* 2011).

Palmyra palm

Arecaceae, Palmae

Borassus flabellifer L. It grows wild in parts of Myanmar, Sri Lanka, South India and parts of tropical Africa. It is a dioecious slow-growing tree that takes 12–15 years before they begin to flower. It has no distinguishing features to identify the sex until flowering. It has fan-shaped leaves. The majority of its economic edible products such as immature endosperm of the fruit called nungu, mesocarp pulp and tuberos seedlings. These are produced only from female palms. The sweet sap from the inflorescence, called neera, is used as a drink and to produce palm sugar. The female palms probably yielding more neera on tapping from the inflorescence. Non-edible products including fibres and wood that are obtained irrespective of whether the palms are male or female (Davis and Johnson 1987). Breeding and crop improvement would be facilitated if sex of the palm could be determined at the early seedling stage to maintain an optimum sex ratio in the plantation. Ponnuswami *et al.* (2008) found that the random amplified polymorphic DNA marker was tightly linked to the sex determination as well as tree stature and high neera yield and was useful for identification of desirable traits in the genotypes.

In India tapping may begin some 15 years after sowing when the flowers are first produced and continues for 30 or 40 years. Tapping is usually carried out in the 4–5 months of the hot dry season (Harrison *et al.* 1985). The unbranched trunk is climbed a minimum of twice a day for each tree for collection of neera and toddy. Jaggery is made from both sugar cane and palmyra palm throughout Asia and parts of Africa. The date palm tree, the coconut palm and kithul trees (*Caryota urens*) are also tapped for producing jaggery. All types of jaggery are made into blocks or pastes by concentrating sugar syrup heated to about 200 °C, traditionally, by heating raw sugar cane juice or palm sap in large, shallow, round bottom vessels. This product is called panela in Colombia and other Latin American countries.

Paniala

Flacourtiaceae, Salicaceae

Flacourtia jangomas (Lour.) Raeusch synonymous with *F. cataphracta* Roxb. is also called Chinese plum and Indian plum. The tree is native to India and commonly cultivated throughout Southeast Asia and in the Philippines. It is an erect, low-branched tree up to 12 m high and has flaking bark and sharp spines on the trunk. Male and female flowers are on separate trees, heavily fragrant, borne in small clusters on new branches. The fruits are round or slightly oval up to 2.5 cm long, dark-maroon to nearly black with greenish to white or amber flesh varying from acid to sweet, containing up to 12 seeds. Morton (1987) gave analysis of fruit from the Philippine as moisture, 78.28%; protein, 0.03%; fat, 0.39%; sugar, 4.86%; ash, 0.94% and acidity, 1.16%. The fruit is fairly rich in pectin and contains 9.9% tannin on a dry weight basis (Morton 1987).

Papaya

Caricaceae

Carica papaya L., also called pawpaw. It probably originated in Central America in the region of southern Mexico, Nicaragua and Costa Rica (Purseglove 1975, de Oliveira and Vitória 2011). It was introduced to many Caribbean islands by the Spanish and other explorers from the Old World and introduced into Hawai'i in the 19th century. Total world production in 2010 was estimated by FAO (2013) as 11,568,346 tonnes.

It is a short-lived fast-growing tree up to 10 m in height. The fruit is a fleshy berry with a large hollow internal cavity containing small, soft, round, black shiny seeds that have a high oil content. The surface has grooves that run the length of the fruit, which are called funicles. There are three types on plant: male, female and hermaphrodite. The Solo cultivar was first identified in 1910 whose fruit from female plants are almost round or ovoid to oblong, while those from hermaphrodite plants are pear shaped or cylindrical. Solo cultivars grown in Hawai'i include Kapoho, Sunrise, Sunset and Laie Gold. Rainbow, Sunup and Laie Gold being produced by genetic modification for resistance to the papaya ring spot virus (PRSV). Solo and Taiwan are commercial papaya cultivars grown in

Brazil (Trindade *et al.* 2001) and in Taiwan cultivars are larger (800–2000 g) than Solo with higher sugar content and thicker skin that makes them less susceptible to transport injuries (Costa and Pacova 2003). The cultivar Maridol originated from Cuba and they are cultivated in Mexico. The Malaysian types are known as Sekai or Hong Kong and Esotika, while the Khack Dum are popular in Thailand (Chan and Paull 2008).

Virus

Several viruses attack papaya including Mosaic and Bunchy Top (Bharath 1969). In the 1940s the PRSV was identified. It causes chlorosis and if young plants are infected they remain stunted and infection of adult plants results in low yield of poor quality fruit. It is primarily spread by aphids and some control can be achieved by controlling the aphids. However, the aphids also feed on other plant species plants and are therefore difficult to control and can transmit the virus as they insert their proboscis. Breeding work was carried out for virus resistance but it had limited success in producing cultivars that were tolerant to the virus. This tolerance meant that they could still produce a viable crop while infected. However, the virus could still be transmitted from these plants to other plants by aphids. In the 1960s Sam Bharath successfully grew papaya selections by giving them optimum cultivation conditions so they began producing fruit some 6 months after sowing and bore fruit for another 6–9 months before succumbing to the virus. In 1985, a group from the US Pacific Basin Agricultural Research Center began work on a genetically modification of papaya (Gonsalves 1998). They isolated and sequenced the gene that coded for the protein coat of PRSV and introduced it into callus cells from the cultivar Sunset, which eventually resulted in a resistant plant line that was successfully field tested in 1991 (Tennant *et al.* 2001). The result was the cultivar SunUp. SunUp was later crossed with the non-genetically modified Kapoho Solo to create the Rainbow cultivar. Both SunUp and Rainbow passed regulatory testing by the United States government and were officially released to farmers in 1998 and in 2000 more than half papayas grown in Hawai'i were transgenic. Rainbow subsequently passed Japanese regulatory testing in 2011. The team in Hawai'i have collaborated in producing PRSV-resistant transgenic

papaya for other countries including Brazil, Jamaica, Venezuela, Thailand, Bangladesh, Uganda and Tanzania (Ferreira *et al.* 2002).

Fruit are a rich source of vitamins A and C, and a good source of the minerals magnesium, potassium, boron and copper with the major carotenoids being lycopene, β -carotene and β -cryptoxanthin (Wall 2006, Furtado *et al.* 2004, Gayosso-Garcia Sancho *et al.* 2010). Papayas ranked fourth in total carotenoid content and vitamin A activity among 39 fruit types (Isabelle *et al.* 2010). Mélo *et al.* (2006) reported that the cultivar Maradol had double the carotenoid content of Formosa and Sunrise, which could be due to location, sunlight exposure and production practices as well as cultivar differences. Total carotenoid content was the highest in ripe, red flesh papaya cultivars (3.0–6.2 mg 100 g⁻¹ fresh weight) because of the abundance of lycopene (Gayosso-Garcia Sancho *et al.* 2010, Schweiggert *et al.* 2011, Wall 2006), while total carotenoid content averaged 0.8–1.1 mg 100 g⁻¹ fresh weight in yellow-fleshed Solo cultivars (Wall 2006). At the earlier stages of fruit development glucose was the principal sugar, but sucrose content was shown to increase during maturation up to levels of 2–6 g 100 g⁻¹ fresh weight in ripe fruit (Gomez *et al.* 2002, Wall *et al.* 2010). The red flesh cultivars Pococi, Maradol, Sunrise and SunUp have high levels of lycopene (1.4–3.7 mg 100 g⁻¹ fresh weight) and lycopene content increased 10-fold during ripening of the cultivar Maradol up to 3.5 mg 100 g⁻¹ in fully ripe fruit (Gayosso-Garcia Sancho *et al.* 2010). Fuggate *et al.* (2010) reported that papaya volatiles consisted of a complex mixture of compounds including esters, with terpenes as the most important volatile constituents. Ester volatile production (ethyl butanoate, ethyl hexanoate, ethyl octanoate, methyl benzoate and ethyl acetate) was low at immature and colour break stages and then increased with the onset of ethylene production, showing a rise coincident with ripening and fruit softening. The volatile compounds of Colombian papayas were also reported to be dominated by esters (de Oliveira and Vitória 2011). The chemical content was given by USDA (2012) in Table 149.

Vitamin C content may increase during maturation and ripening and then decline during storage. It also varied with climate, harvest season, soil type and production practices (Charoensiri *et al.* 2009,

Table 149 The composition of papaya fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	88.06 g	Thiamine	0.023 mg
Energy	43 kcal	Riboflavin	0.027 mg
Protein	0.47 g	Niacin	0.357 mg
Total lipid (fat)	0.26 g	Vitamin B-6	0.038 mg
Carbohydrate, by difference	10.82 g	Folate	37 µg DFE
Total dietary fibre	1.7 g	Vitamin B-12	0.00 µg
Total sugars	7.82 g	Vitamin A	47 µg RAE
Calcium	20 mg	Vitamin A	950 IU
Iron	0.25 mg	Vitamin E (α-tocopherol)	0.30 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	10 mg	Vitamin D	0 IU
Potassium	182 mg	Vitamin K (phylloquinone)	2.6 µg
Sodium	8 mg	Fatty acids, total saturated	0.081 g
Zinc	0.08 mg	Fatty acids, total monounsaturated	0.072 g
Total ascorbic acid	60.9 mg	Fatty acids, total polyunsaturated	0.058 g

Gayosso-Garcia Sancho *et al.* 2010, Tripathi *et al.* 2011, Wall 2006). Othman (2009) harvested fruit over the season in Tanzania and found that their ascorbic acid content increased during the season and also during ripening at room temperature over 8 days. He found that the reducing sugars and total sugars content increased during ripening, while the sucrose content decreased during this period as was also found in Indian by Zaman *et al.* (2006). The papaya fruit also shows a seasonal variation in sugar content. The highest total sugars content were in early season papaya fruits, while the lowest were in late season fruits. This was reflected in the TSS content of the Tanzanian papaya fruits, which increased during the ripening process. Similar results were reported by Bron and Jocomino (2006) for Brazilian papaya fruits. The papaya fruit also exhibited a seasonal variation in TSS content. Higher TSS amounts were in early-season fruits, while the lowest amounts were in late-season fruits. Early-season Tanzanian fruits had the highest TA, while late-season fruits exhibited the lowest TA. During ripening of the papaya fruit there was a decrease in TA. Such a decrease in acidity during ripening of papaya has been reported in Brazil by Bron and Jocomino (2006).

Harvesting and packing

The fruit turns from green to yellow during ripening. If the fruit is harvested when they are still green it may be possible to develop the fruit colour after harvest but not all the flavour characteristics (Thompson and Lee 1971). If the fruit is harvested just as the yellow colour begins to show the funicles, it can eventually ripen to an acceptable flavour. Pereira *et al.* (2009) found that less mature fruit had turgid, regular shaped parenchyma cells and relatively little intercellular spaces, but as the fruit matured there was separation of cell walls and pectic substance accumulation into the intercellular spaces. In an experiment fruits of the cultivar Pakchong 1 were hand harvested at the mature green stage, the 5% yellow and the 15% yellow stages and then ripened at 25 °C and 80% r.h. by Kulwithit and Kositrakun (1998). When ripe, the 15% yellow fruits had the highest flesh firmness of 57.4 N, TSS content of 13.1%, TA of 0.14% and ascorbic acid content of 179.0 mg 100 ml⁻¹ juice, but there were no significant differences between the mature green and the 5% yellow fruits. Delayed light emission has also been used on papaya by Forbus *et al.* (1987) to grade fruit into different maturity groups after harvesting. Body transmittance spectroscopy was used for optical grading into ripening and non-ripening groups (Birth 1983). With this method it was possible to grade fruits that were indistinguishable by visual examination.

Harvesting is carried out by hand. Fruits harvested by cutting the fruit stalk and packing them into export cartons in the field had a lower incidence of rotting during subsequent storage than fruit harvested by twisting and pulling it from the plant and transporting them to a packhouse (Table 150). Latex that exudes from the cut stalk contains two proteolytic enzymes papain and chymopapain and can cause staining of the fruit surface (Teixeira da Silva *et al.* 2007). It may therefore be important for the fruit to be placed stalk downwards until this exude stops before they are packed.

Field packing directly into cartons reduces the amount of handling and therefore the potential damage to the fruit. However, many supermarkets will not accept fruit that have been packed directly in the field, because they are concerned that the cartons will be contaminated by the soil. Contamination of the fruit can also occur in packhouses. Jaxsens *et al.* (2010) reported that potential sources of food

Table 150 Effect of harvesting method on various parameters after storage of Solo papaya for 21 days at 7 °C followed by 6 days at 25–28 °C (source: adapted from Thompson and Lee 1971)

Harvesting method	Weight loss (%) ^a	Soluble solids (%)	Flavour score 0–11 ^b	Number of fungal lesions ^c
Normal	5.4	9.2	5.6	13.6
Careful	4.1	10.5	6.7	4.2

^aAs a percentage of the weight at harvest.

^bWhere 0 = very poor and 11 = excellent.

^cMean number per fruit.

borne pathogens in packhouses included deficiencies in worker hygiene and the use of animal manure for fertilizer in the field. *Salmonella enteric* serotype Litchfield contamination occurred on papaya fruit in Australia because of untreated river water being used to wash the fruit and dilute the fungicide used on fruit before they were packed (Gibbs *et al.* 2009). The USA Food and Drug Administration analysed samples of papaya imported from Mexico from 12 May 2011 to 18 August 2011 and found *Salmonella agona* USE *Salmonella enterica* subsp. *enterica* serovar Agona in 33 samples out of a total of 211 from 28 different farms and included almost all the major papaya producing regions in Mexico. It was reported that to gain future entry into the United States, producers would have to prove that shipments of papaya were not contaminated with *Salmonella* using laboratory analysis, with five consecutive salmonella-free shipments over a period of time (Anonymous 2 n.d.).

1-MCP

Hofman *et al.* (2001) showed that exposure of the cultivar Solo to 1-MCP at 25 µl L⁻¹ for 14 h at 20 °C increased the number of days to ripening by 15.6 days (325%) in compared with non-treated fruit. They concluded that 1-MCP treatment had the potential to reduce the risk of premature fruit ripening because of accidental exposure to ethylene. Bayogan *et al.* (2010) found that treatment with 1-MCP at 100 nl L⁻¹ resulted in a longer shelf life for the cultivar Kapoho, with less diseased fruit. However Fabi *et al.* (2007) compared non-treated, ethylene or ethylene + 1-MCP-treated Golden papayas and found that 1-MCP could decrease the quality of fruit and that even the use of ethylene for initiating ripening could result in lower quality when compared to that of fruit allowed to ripen 'naturally'.

Hofman *et al.* (2001) also found that 1-MCP could have a negative affect since treatment was associated with slightly higher severity of external blemishes and severity of rots compared to those not treated. Osman *et al.* (2010) reported that 1-MCP treatment increased the incidence of postharvest fungal diseases during ripening. In contrast when papayas at the 25–30% yellow stage were exposed to 100 μL 1-MCP and dipped in the biocontrol agent *Bacillus amyloliquefaciens* PPCB004, disease incidence and severity were lower and overall fruit quality higher than for fruit not treated or treated only with 1-MCP (Khan *et al.* 2002). Harvest maturity has been shown to affect the response of papayas to 1-MCP. Fruit treated at colour break stage with 50–1000 nL L^{-1} 1-MCP did not soften completely but developed an elastic or rubbery texture. In contrast, fruit treated at 25% yellow skin ripened normally. Those treated at less than 25% yellow skin failed to ripen completely, had a reduced respiratory peak and delayed ethylene production (Manenoi *et al.* 2007). Fruit treated at over 30% yellow colour stage had slightly delayed ripening and skin colour development, but softened normally. Papayas treated with 1-MCP showed less PME activity and a lower content of soluble pectin and delayed fruit softening (Asmar *et al.* 2010). 1-MCP may reduce cellular disintegration resulting from oxidative stress by enhancing some antioxidant enzyme activities (superoxide dismutase, ascorbate peroxidase and catalase) and preventing degradation of cell wall components associated with ethylene that lead to tissue softening (Ali *et al.* 2005).

Postharvest physiology

It is a climacteric fruit (Biale and Barcus 1970). In Malaysia Broughton *et al.* (1978) and Nazeeb and Broughton (1978) showed that scrubbing ethylene from the store containing the cultivar Solo Sunrise had no effects on their storage life, but they stated that at 20 °C with 5% CO_2 and ethylene removal was the optimum condition for storage for 7–14 days. In later work it was shown that ethylene application could accelerate ripening by 25–50% (Wills 1990). Ethylene production rates in ripening fruit were 6–10 $\mu\text{L kg}^{-1} \text{h}^{-1}$ (Paull 1993). Ethylene-treated papayas ripened faster and more uniformly in terms of skin greening, softening and flesh colour (An

Table 151 Respiration rate of papaya fruit at different temperature (source: adapted from An and Paull 1990)

Temperature (°C)	$\text{mg CO}_2 \text{ kg}^{-1} \text{h}^{-1}$
5	4–6
15	15–22
20 – colour break	9–18
20 – ripe	70–90

and Paull 1990). Since they ripen from the inside outwards, the effect of ethylene treatment is to accelerate the rate of ripening of the mesocarp tissue nearer the skin that has not started to ripen. They did not recommend ethylene to be used commercially, as rapid softening severely limited available marketing time. They gave respiration rates in Table 151.

The TSS content of mature fruit should be at least 11.5% to meet market grade (HDOA 2005, Postharvest Handling Technical Bulletin 2003). TA was reported to increase as fruit ripened to about 75% yellow skin colour and decreased thereafter (Lazan *et al.* 1989, Bron and Jocomino 2006, Schweiggert *et al.* 2011). However, in the cultivar Pluk Mai Lie, the TA did not differ significantly throughout the ripening process (Fuggate *et al.* 2010) and the malic acid content was reported to decrease during ripening (Chan *et al.* 1979, Selvaraj and Pal 1982). During ripening-related changes in skin and flesh colour, the TSS increased in the pulp while it softened from a degradation of cell wall components and an accumulation of lower molecular weight carbohydrates (Schweiggert *et al.* 2011). Fruit softening is due to depolymerization of pectin in the cell walls, in which high-molecular-weight-insoluble pectin is converted into soluble polyuronides (John and Dey 1986, Lazan *et al.* 1995). This ripening-induced softening is catalysed by the enzymes, PG, PME, β -galactosidase and cellulase (D'Innocenzo and Lajolo 2001, Pérez *et al.* 2010). A direct relationship was reported between polygalacturonase and xylanase activity and fruit softening (Paull and Chen 1983). They also reported increased xylanase activity solubilized hemicelluloses in the cell wall and resulted in decreased fruit firmness at the 40–60% yellow ripe stage indicating that degradation of hemicellulose, as well as pectin, may play a significant role in papaya fruit softening.

Chilling injury

Fruit will freeze at about -1.2 to -0.9°C (Wright 1942). Papaya fruit are sensitive to chilling injury. Symptoms include sensitivity to attack by *Alternaria* sp., failure to ripen normally, and sometimes water-soaked tissues. Marangoni *et al.* (1996) reported that chilling injury was associated with changes in chemical composition of cell membranes, in particular the fatty acid composition. They found that temperature affected the degree of membrane changes from a gel phase to a liquid crystalline phase and as a result of this transition, the cell membranes lost integrity and cell compartmentalization was weakened. Chilling injury was also accompanied by lipid degradation because of the activity of lipoxygenase, for which linoleic acid and linolenic acid were common substrates (Maalekuu *et al.* 2006). Kader (1985) stated that the critical temperature above which chilling injury will not occur could be as low as 6°C . In contrast Nazeeb and Broughton (1978) found that chilling injury could occur during storage at 15°C . They also indicated a preferred storage temperature of 20°C , since fruit kept for more than 7 days at 15°C and below failed to ripen. The severity of chilling injury depended on cultivar and maturity stage with fruit at the colour break stage being stored at 7°C up to 14 days without chilling injury and the fruit ripened normally at ambient temperature, whereas the mature green fruit had chilling injury symptoms (Chen and Paull 1986, Chan 1988). A prestorage treatment of storage at 45°C for 6 h was reported to reduce chilling injury symptoms for the cultivar Sunrise stored at 5°C by delaying the decline of superoxide dismutase and catalase activities and suppressing an increase of peroxidase activity (Huajaikaew *et al.* 2005). Dos Reis Neto *et al.* (2011) reported that ethylene absorbers inside MA packaging of papayas controlled chilling injury after 20 days storage at 7°C . Treatment of Sunrise with methyl jasmonate (10^{-4} M) and MA packaging reduced chilling injury (González-Aguilar *et al.* 2003), which might be due to a mechanism that involves an increase in abscisic acid and polyamine levels (Wang and Buta 1999).

Storage

At room temperature of 20°C and 60% r.h. they could be kept for 2–3 days (Mercantilia 1989). Refrigerated storage recommendations include

- $4\text{--}5.5^{\circ}\text{C}$ and 85–90% r.h. for 5 weeks (Anonymous 1967);
- 7.2°C and 85–90% for 1–3 weeks (Lutz and Hardenburg 1968);
- 13°C for 21 days with subsequent normal ripening at 26°C (Thompson and Lee 1971);
- 10°C and 85–90% r.h. for 3–4 weeks with 5.8% loss for green fruit (Pantastico 1975);
- 8.3°C and 85–90% r.h. for 2–3 weeks for ripe fruit (Pantastico 1975);
- 10°C and 90% for 2–3 weeks (Mercantilia 1989);
- 7°C and 85–90% r.h. for 1–3 weeks (Hardenburg *et al.* 1990);
- 10°C and 90% r.h. for 3–4 weeks for green fruit (Snowdon 1990);
- 7°C and 90% r.h. for 2–3 weeks for turning fruits (Snowdon 1990);
- 10°C and high humidity for 14 days subsequently ripened normally at 25°C in 4 days (Lam 1990);
- 12.2°C and 85–90% r.h. for 7–21 days (SeaLand 1991).
- Chen and Paull (1986) studied storage in a range of temperatures from 7 to 13°C with 90–95% r.h. They found that at $7\text{--}10^{\circ}\text{C}$ storage life was limited by chilling injury, while at $10\text{--}13^{\circ}\text{C}$ ripening was slow. Fruit harvested as the colour is just beginning to change could be stored at 7°C for 14 days and will ripen normally when transferred to room temperature while those harvested when fully yellow could be stored for more than 1 week at $1\text{--}3^{\circ}\text{C}$ (Thompson and Lee 1971, Chen and Paull 1986).

Controlled atmosphere storage

CA storage recommendations are quite diverse and include

- 13°C for 3 weeks in 5% CO_2 with 1% O_2 followed by ripening at 21°C gave fruit that were in a fair condition with little or no decay and were of good flavour (Hatton and Reeder 1968).
- 18°C with 10% CO_2 for 6 days for the cultivar Solo resulted in reduced decay compared to fruits stored in air, but they decayed rapidly when removed to ambient (Akamine 1969).
- 13°C in 1% O_2 for 6 days or 1.5% O_2 for 12 days ripened about 1 day slower than those stored in air (Akamine and Goo 1969).
- 10°C with 2% O_2 and 98% nitrogen was shown to extend the storage life in Hawai'i compared to

storage in air at the same temperature (Akamine and Goo 1969).

- 10 °C and 85–90% r.h. with 5% CO₂ and 1% O₂ for 21 days (Pantastico 1975).
- 2–5% O₂ and 5–8% CO₂ (Nazeeb and Broughton 1978).
- 10–15 °C with 5–10% CO₂ and 5% O₂ had a fair effect but was said to be ‘not being used commercially’ (Kader 1985, 1989, 1992).
- 1.5–5% O₂ delayed ripening of the cultivar Kapaho Solo compared to those stored in air and that there was no further benefits on storage by increasing the CO₂ level to either 2 or 10% (Chen and Paull 1986).
- 18 °C with 10% CO₂ reduced decay (Hardenburg *et al.* 1990).
- 16 °C with 5% CO₂ and 1.5–2% O₂ for 17 days for the cultivar Known You Number 1 compared to only 13 days in air (Sanket and Maharaj 1989).
- 16 °C with 5% CO₂ and 1.5–2% O₂ for the cultivar Tainung Number 1 gave a maximum life of 29 days compared to 17 days stored in air (Sanket and Maharaj 1989).
- 12.2 °C and 85–90% r.h. with 10% CO₂ and 5% O₂ SeaLand (1991).
- 12 °C with a range 10–15 °C with 5–8% CO₂ and 2–5% O₂ (Kader 1993).
- 10–15 °C with 5–8% CO₂ and 2–5% O₂ (Bishop 1996).
- 10 °C with 8% CO₂ and 3% O₂ for 36 days for the cultivar Solo and still have an adequate shelf life of 5 days at 25 °C (Cenci *et al.* 1997).
- 7–13 °C and 85–90% r.h. with 2–5% O₂ and 5–8% CO₂ for 1–3 weeks (Burden 1997).
- Low O₂ (1–5%), with or without high CO₂ (2–10%), reduced decay and delayed ripening (Hatton and Reeder 1968, Chen and Paull 1986). CO₂ at 30% adversely affected internal colour, aroma and flavour, while there was no residual effect of 10% CO₂ on decay control, though skin degreening was delayed. At 10 °C, fruit can be stored for 36 days in 8% CO₂+ 3% O₂ and still have shelf life of 5 days at 25 °C (Cenci *et al.* 1997). Ethylene removal prior to storage has shown variable results (Nazeeb and Broughton 1978).

Modified atmosphere packaging

Wills (1990) reported that MA packaging extended their storage life. Rohani and Zaipun (2007) stored

the cultivar Eksotika sealed in 0.04-mm-thick LDPE bags at 10–12 °C for 14 days. There were minor changes in skin colour but the packaging reduced disease incidence and they ripened normally within 3–4 days at ambient temperature when removed from the package. They suggested that this packing method could be used for exporting fruit. For maximum storage life in plastic films it is advantageous to include potassium permanganate as an ethylene absorbent (Nazeeb and Broughton 1978). The cultivar Rathna was submerged in hot water at 49 °C for 20 min, then sprayed with 5% ethanol, for disinfection of the fruit surface and packaging in LDPE containing potassium permanganate and successfully stored for 12 days (Jayathunge *et al.* 2011). Packaging the cultivar Golden in 0.25-mm-thick LDPE bags with ethylene absorber sachets containing potassium permanganate was effective in controlling chilling injury after storage at 7 °C (Dos Reis Neto *et al.* 2011).

Hypobaric storage

Fruit stored at 10 °C and 98% r.h. and pressure of 20 mm Hg ripened more slowly and had less disease development than fruit at atmospheric pressure (Alvarez 1980).

Ripening

Optimum ripening was achieved at 21.1–26.7 °C (Wardlaw 1937). Wills *et al.* (1989) recommended ripening at 21–27 °C with no ethylene. In South America fruit are sometimes lightly scored on the skin, which is said to hasten ripening, probably because it stimulates the production of wound ethylene. Lam (1990) reported that fruits kept at 25 °C for 11 days ripened normally. Schweiggert *et al.* (2011) and Tripathi *et al.* (2011) reported that the nutritive value of fully ripe papayas was similar for fruit allowed to ripen on the tree or those that had been ripened postharvest and for transgenic and non-transgenic cultivars. Kulwithit and Kosittrakun (1998) had also found that there was no significant difference in eating quality among ripened fruits of the various harvest maturities, although Thompson and Lee (1971) had previously found that fruit harvested before they began to turn yellow were of inferior eating quality. This would be confirmed by Fugate *et al.* (2010) who found that ripening was associated with biosynthesis of aroma volatiles, but fruit

harvested while still green did not attain their full aroma.

Diseases

The major disease is Anthracnose (*Colletotrichum gloeosporioides*, *Glomerella cingulata*), which was shown to develop when fruit had 25% or more skin yellowing (Wardlaw *et al.* 1939a). Snowdon (1990) described the symptoms as spots on green fruits that are generally dark brown to black with a pale margin and lenticular in shape. The affected areas increased in size and become sunken and coalesce to form large spots. Other postharvest diseases include

- Botryodiplodia rot or stem end rot (*Botryodiplodia theobromae* = *Diplodia natalensis*). Water-soaked spot increases and turns into dark-brown lesion irregular in outline having greenish water-soaked margin. At later stages the centre of the lesion becomes depressed and dark greyish mycelial growth may appear on the surface.
- Stem-end rot, or ascochyta rot (*Ascochyta carica papayae* = *A. caricae* = *Mycosphaerella* sp.). Fruit rot often starts from the stem end. Water-soaked lesion increases in size and turns dark brown to blackish in colour. At later stage numerous dark pycnidial bodies may appear on the surface of the lesion.
- Brown spot (*Alternaria alternata* = *A. tenuis*). As the lesions increase, the colour changes to greyish-brown. At later stage the surface of lesion may become covered with dark-brown conidiophores and conidia.
- Soft rot (*Fusarium acuminatum*). Water-soaked spots enlarge and turn light brown in colour. At later stages the centre of the lesion becomes depressed. Often a white mycelial growth appears on the surface.
- Rhizopus rot or soft watery rot (*Rhizopus stolonifer* = *R. nigricans*). Water-soaked lesions with irregular margins spread. At later stage the lesion turns brown and white mycelial growth sporangiophores appear on the surface. Finally the fruit collapses with watery exudate and emits a foul odour. *Rhizopus* infections occur and are through breaks in the cuticle usually as a result of mechanical or fruit fly damage.
- Soft fruit-rot (*Pythium aphanidermatum*). Water-soaked lesions spread and turn brown. White

mycelial growth appears on the lesion (Snowdon 1990).

Vapour heat treatment to control pests and diseases is 43 °C in saturated air for 8 h and then holding the temperature for a further 6 h was recommended by Jacobi *et al.* (1993). Vapour heat treatment can cause injury to some fruits. For control of fruit flies in Hawai'i the fruit were first exposed to 43 °C and 40% r.h. for 11 h followed by 43 °C and 100% r.h. for 8³/₄ h (Pantastico 1975). The initial exposure of fruit to the lower humidity was said to increase the number of insects killed and the tolerance of the fruit to the treatment. Storage at 20 °C with 0% CO₂ and less than 0.4% O₂, as a method of fruit fly control, resulted in increased incidence of decay, abnormal ripening and the development of off flavour after exposure to 5 days (Yahia *et al.* 1989).

Maharaj and Sankat (1990) used hot water treatment at 48 °C for 20 min or hot water plus benomyl (1.5 g L⁻¹) at 52 °C for 2 min to control of anthracnose caused by *Colletotrichum gloeosporioides*. Akamine and Arisumi (1953) recommended hot water at 49 °C for 20 min and Schirra *et al.* (2000) recommended including thiabendazole with the hot water. In Yemen the control of anthracnose on papaya was achieved by preharvest sprays with Metiram 80% wettable powder at 200 g 100 L⁻¹ of water or Propineb 70% at 200 g 100 L⁻¹ of water or copper oxychloride 50% wettable powder at 400 g 100 L⁻¹ water applied at 7–10 days intervals (Kamal and Agbari 1985). At 18 °C an atmosphere containing 10% CO₂ reduced decay during storage (Hardenburg *et al.* 1990).

Maqbool *et al.* (2012) found that postharvest treatment with 0.05% lemongrass oil at 0.05% or cinnamon oil at 0.4% showed fungicidal effects against *C. gloeosporioides*, but the combination of 10% gum arabic with 0.4% cinnamon oil gave even better control. Bosquez-Molina *et al.* (2010) carried out *in vitro* studies on the control of *C. gloeosporioides* and *Rhizopus stolonifer* by thyme and Mexican lime essential oils with both giving control of the fungi with thyme oil being more effective than Mexican lime oil. For *in vivo* tests, fruit were dipped in the thyme and Mexican lime essential oils before and after inoculation. Treatment reduced decay caused by *C. gloeosporioides* by up to 50% and *R. stolonifer* by up to 40% compared with the 100% infection in non-treated papayas. Additionally they found that

fruit immersed in mesquite gum emulsion, which had been formulated with both 0.1% thyme essential oil and 0.5% Mexican lime essential oil, had no disease incidence caused by *C. gloeosporioides* during storage.

Jayathunge *et al.* (2011) reported that postharvest losses can be high for fresh papaya, with an average of 46% in Sri Lanka.

Pests

Fruit flies are quarantine insects that can limit the marketability of papaya. Fruit flies that infest papaya include *Anastrepha ludens*, *A. suspense*, *Bactrocera curcurbitae*, *B. dorsalis*, *B. papayae*, *Ceratitis capitata* and *Toxotrypana curvicauda*. Scale insects, mites, aphids, thrips, leafhoppers and whiteflies also may impede exports or lead to rejections by port inspectors. Therefore, fresh papaya must receive an approved quarantine treatment before export to prevent the spread of exotic pests. The aim of the quarantine treatment is to kill or sterilize infecting insects to meet phytosanitary requirements. Hot water immersion, vapour heat, forced hot air and irradiation are approved quarantine treatments for fruit flies and surface pests on papayas (Pantoja *et al.* 2002, Reiger 2006, Yahia 2006). Couey and Hayes (1986) and Moy (1993) described hot water treatment within 18 h of harvest by immersing quarter ripe papaya for 30 min at 42 °C followed by 20 min at 49 °C and finally hydrocooling with water spray at ambient temperature for disinfecting of tephritid fruit fly eggs in Hawai'ian papayas. However, treatment killed only eggs and early instar larvae near the fruit surface and there may have larvae towards the centre, which might not be killed by the treatment. Vapour heat treatment uses moist hot air with an exposure time to reach 47.2 °C over a period of 6–8 h, which killed both the fruit fly eggs and larvae (Moy 1993, Armstrong and Mangan 2007). Forced hot air treatment is similar but hot air is used at 45–65% r.h. with the same objective to retain 47.2 °C for 4–7 h (Armstrong *et al.* 1989, 1995).

Gamma, X-ray, or electron beam irradiation has been approved by the USA Food and Drug Administration at doses up to 1000 Gy for the preservation and disinfestation of fresh fruits and vegetables imported into the United States (FDA 1986). USDA APHIS has approved minimum generic irradiation doses of 150 Gy for control of tephritid fruit flies

and 400 Gy for all insects except pupa and adult Lepidoptera (APHIS 2006). However in commercial practice, Follett *et al.* (2007) reported that papayas were treated with 400 Gy to avoid the chance of rejections because of the presence of surface pests. Papayas at the mature-green or quarter-ripe stage can tolerate up to 1000 Gy irradiation without changing in nutritional or sensory quality or developing surface scald (Boylston *et al.* 2002, Moy *et al.* 1973, Paull 1996). Irradiation may delay ripening and softening, but its effect depends on the maturity stage of treated papaya fruit (Miller and McDonald 1999). Papayas irradiated at the 25–30% yellow stage with 500–1000 Gy retained firmness for 2 days longer than control fruit (Zhao *et al.* 1996). Fruit with less than 25% yellow colour developed skin scald when stored at 10 °C immediately after irradiation, but injury was prevented by delaying cold storage for 12 h (Paull 1996).

Papayuela

Caricaceae

Carica pubescens (A. DC.) Solms-Laub., *C. candamarcensis* Hook. f. There is some confusion as to the species of this plant. Purseglove (1968) referred to mountain papaya as *C. candamarcensis*, while Morales and Duque (1987) and Alarcon *et al.* (1998) referred to mountain papaya and papayuela as *C. pubescens*.

The fruit is a fleshy oval berry with acid flesh and a central core of seeds, and is up to about 10 cm long, with a green skin as it develops turning yellow at maturity. It is similar to the papaya (*C. papaya*) but it is frost resistant and grows up to 2500 m above sea level in Colombia and Ecuador. It is rarely eaten fresh as it is quite sour and is usually made into jam or puree. Morales and Duque (1987) found at least 53 volatile components in the fruit of which 45 were positively identified. Esters were the most abundant group of compounds (63% of the extract), followed by alcohols (30%). The major aroma compounds were ethyl butyrate, butanol, ethyl acetate, methyl butyrate and butyl acetate. Papaya is a climacteric fruit and therefore papayuela probably is also.

Maturity is when the skin of the fruit just begins to turn from green to yellow and it feels soft to the touch. A refrigerated storage recommendation was 8–12 °C and 85–90% r.h. for 1–2 weeks (Amezquita 1973).

Passionfruit

Passifloraceae

Passiflora edulis Sims, also called maracuyá. There are two distinct forms: the purple passionfruit (*P. edulis* forma *edulis* L.) and the yellow passionfruit (*P. edulis* forma *flavicarpa* Degener).

Morton (1987) stated that the purple passionfruit was native from southern Brazil through Paraguay to northern Argentina and the yellow form is of unknown origin, or perhaps native to the Amazon region of Brazil, or is a hybrid between *P. edulis* and *P. ligularis*. Cytological studies have not borne out the hybrid theory and some people believe the yellow passionfruit is a chance mutant that occurred in Australia. Morton also quotes E.P. Killip (1938) who described *P. edulis* in its natural range as having purple or yellow fruits. In Australia, about 1943, a widespread invasion of *Fusarium* wilt killed purple passionfruit vines and the yellow passionfruit was adopted as a rootstock since it is both wilt-resistant and nematode-resistant and does not sucker from the roots.

Passiflora are woody perennial vines mostly native to the tropical Americas with a few from Asia, Australia and one from Madagascar (Purseglove 1975). They climb with the aid of long unbranched tendrils produced in each leaf axil. The flowers are up to about 7 cm in diameter and with long filament-like rays. The edible portion is the fruit, which are globular to oval in shape and have a dry brittle skin, is the gelatinous aromatic pulp containing numerous seeds. Many species are grown for ornamental purposes especially *P. caerulea*. The purple passionfruit grows well in higher altitudes in the tropics and has the better flavour, while the yellow passionfruit grows better in the lowlands. The yellow form has a more vigorous vine and generally larger fruit than the purple, but the pulp of the purple is less acid, richer in aroma and flavour, and has a higher proportion of juice (35–38%). The purple form has black seeds, the yellow, brown seeds. (Morton 1987)

Morton (1987) reported that the yellow passionfruit was an excellent source of niacin and a good source of riboflavin but had somewhat less ascorbic acid than the purple but higher total acid (mainly citric) and carotene. Free amino acids in purple passionfruit juice were: arginine, aspartic acid, glycine, leucine, lysine, proline, threonine, tyrosine and

Table 152 The composition of purple passionfruit, pulp and seeds for 100 g⁻¹ fresh weight (source: Morton 1987)

Calories	90	Phosphorus	64 mg
Moisture	75.1 g	Iron'	1.6 mg
Protein	2.2 g	Sodium	28 mg
Fat	0.7 g	Potassium	348 mg
Carbohydrates	21.2 g	Vitamin A	700 IU
Fibre	–	Thiamine	Trace
Ash	0.8 g	Riboflavin	0.13 mg
Calcium	13 mg	Niacin	1.5 mg
		Ascorbic acid	30 mg

valine. Carotenoids in the purple form were 1.16% and in the yellow, 0.058%. Flavonoids in the purple were 1.06% and in the yellow, 1.00%. Alkaloids in the purple were 0.012% and in the yellow, 0.70%. Starch content in purple passionfruit juice was 0.74% and in the yellow, 0.06%. The chemical content was given by Morton (1987) in Table 152.

Harvesting

The fully mature fruit have the best flavour, but a short shelf life. Wardlaw (1937) therefore recommended that they should be harvested when they are about three quarters yellow or purple. Immature fruits do not ripen properly after harvest. The purple passionfruit, forma *edulis*, may become reddish and shrivel if harvested too immature (Wardlaw 1937).

Waxing and pretreatments

Gama *et al.* (1991) reported that wax (autocitrol), thiabendazole or sodium hypochlorite application had a no beneficial effect on fruit storability. In contrast Gomez (2000) found that wax (Primafresh C) extended the shelf life of fruits, reduced weight losses and maintained an adequate external appearance during storage at 12 °C and 80% r.h. Purple passionfruit coated with 1% Semperfresh (an edible mixture of sucrose esters of fatty acids and carboxymethyl cellulose) had lower storage weight losses, less shrivelling and were sweeter but had more fungal disease than untreated fruit (Ssemwanga 1990).

Postharvest physiology

Akamine *et al.* (1957) reported that it was climacteric and described how *P. edulis*, stored at 25 °C, reached

a climacteric peak of CO₂ production after 13–14 days. In contrast their respiratory pattern led to it being classified as an indeterminate fruit by Biale and Barcus (1970).

Storage

Storage below 10 °C led to chilling injury in the form of blood red discoloration of the skin quickly followed by mould attack (Wardlaw 1937). The major limitations to storage are fermentation of the pulp, shrivelling and fungal decay (Wardlaw 1937), although it was found that moisture was lost mainly from the skin rather than the pulp, and shrivelled samples had a similar flavour to those of smooth ones (Ssemwanga 1990). In storage trials on yellow passionfruit at 5, 10 and 15 °C soluble solid percentage did not change over a 45 day period at 5 or 10 °C but decreased linearly at 15 °C and the external appearance of fruit deteriorated rapidly at 5 and 15 °C (Arjona *et al.* 1992). Fruits used in the experiments were vine ripened and the percentage of pulp increased linearly during storage at 5 °C, did not change at 10 °C but at 15 °C it increased up to 30 days then decreased from then to the end of the experiment which was 45 days (Arjona *et al.* 1992). Storage of vine-ripened yellow passionfruit at 29 ± 2 °C retained their fresh, characteristic, ester-type aroma (ethyl butanoate and ethyl hexanoate) for only 3 days after harvest. There was a continuous increase in the concentration of ethyl acetate over the 15 days of storage. Hexyl butanoate levels were highest after 3 days of storage, decreasing thereafter. Benzaldehyde and hexanol levels decreased after 9 days of storage but 2-heptanone increased continuously during storage (Narain and Bora 1992.). At room temperature of 20 °C and 60% r.h. they could be kept for about 1 week (Mercantilia 1989). Other refrigerated storage recommendations include:

- 5.5–7 °C and 80–85% r.h. for 4–5 weeks (Anonymous 1967);
- 5.6–7.2 °C and 85–90% r.h. for 3 weeks with 32% weight loss for purple passionfruits (Pantastico 1975);
- 8 °C and 90% r.h. for 3–4 weeks (Mercantilia 1989);
- 7–10 °C and 85–90% r.h. for 3–5 weeks (Snowdon 1990);

- 12.2 °C and 90–95% r.h. for 14–21 days (SeaLand 1991);
- Morton (1987) reported that under-ripe yellow passionfruits can be ripened and stored at 20 °C and 85–90% r.h. Ripening was too rapid at 30 °C. Ripe fruits kept for 1 week at 2.2–7.2 °C. Fruits stored in unperforated, sealed, polyethylene bags at 23.1 °C remained in good condition for 2 weeks. Coating with paraffin and storing at 5–7 °C and 85–90% r.h. prevented wrinkling and preserved quality for 30 days.

Modified atmosphere packaging

Storage in plastic bags can prolong their storage life. In Colombia the fruits of the cultivar Degener were considered unsaleable after only 5 days at a mean ambient temperature of 23 °C and 76% r.h., but after storage for 14 days in the non-perforated and perforated bags there were 99% and 80% of saleable fruits respectively (Salazar and Torres 1977). Packing purple passionfruit fruits in PE bags reduced weight loss and the fruits stored well at 6 °C for 42 days. Ssemwanga (1990) also showed that storage of fruit in PE bags of 25 µm thick reduced moisture loss and shrivelling and extended their storage life to 28 days without adversely affecting the internal quality.

Ripening

Akamine *et al.* (1957) found that adding 500 µl L⁻¹ ethylene during storage at 25 °C resulted in the climacteric peak being reached in only 2 days compared to 13–14 days in fruits without ethylene.

Peaches

Rosaceae *Prunus persica* L. Batsch

Prunus persica L. Batsch. They originated in China and they were probably taken to the Middle East through the trade routes that extended to Turkey and Iran. They are cultivated in temperate regions including Mediterranean countries, Japan, South Africa, Australia, New Zealand and United States. Peach trees require a certain number of chilling hours in order to break dormancy and low chill cultivars have been selected for production in warmer climates. It is a small willow deciduous tree that produces small

Table 153 The composition of peach fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	88.87 g	Thiamine	0.024 mg
Energy	39 kcal	Riboflavin	0.031 mg
Protein	0.91 g	Niacin	0.806 mg
Total lipid (fat)	0.25 g	Vitamin B-6	0.025 mg
Carbohydrate, by difference	9.54 g	Folate	4 µg DFE
Total dietary fibre	1.5 g	Vitamin B-12	0.00 µg
Total sugars	8.39 g	Vitamin A	16 µg RAE
Calcium	6 mg	Vitamin A	326 IU
Iron	0.25 mg	Vitamin E (α-tocopherol)	0.73 mg
Magnesium	9 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	20 mg	Vitamin D	0 IU
Potassium	190 mg	Vitamin K (phyloquinone)	2.6 µg
Sodium	0 mg	Fatty acids, total saturated	0.019 g
Zinc	0.17 mg	Fatty acids, total monounsaturated	0.067 g
Total ascorbic acid	6.6 mg	Fatty acids, total polyunsaturated	0.086 g

white or pink flowers on 1-year old wood. The fruit is a drupe and is classified as climacteric. It will freeze at about -1.7 to -1.3 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 153. Total world production for peaches and nectarines in 2010 was estimated by FAO (2013) as 20,528,283 tonnes.

Harvesting and handling

Bedford and Robertson (1955) showed that peaches harvested too immature tended to develop a stale 'off' flavour when ripe. Also Phillips and Armstrong (1967) stated that immature fruits may be rubbery and astringent while over mature fruit tended to be stringy. The assessment of harvest maturity by skin colour changes usually depends on the judgement of the harvester but colour charts are used for some cultivars. A colour difference meter, Minolta Chroma CR-200, (Figure 3) was successfully used to measure the surface colour of peaches and relate this to fruit pigments, soluble solids content and firmness (Kim *et al.* 1993). In India the fruits of cultivar Flordasun were found to attain maturity 72–75 days after fruit set. Fruit firmness of around 6.5 pounds per square inch, was found to be a good index of harvest maturity together with TSS, acidity and total sugars of about

10.9%, 0.50, 7.90%, respectively (Badiyala 1998). In studies in Turkey it was shown that the firmness of peaches changed significantly during the harvest season and these changes could be measured using a Magness and Taylor type pressure tester (Figure 5). A device which applied low pressure air to opposite sides of fruit and then measured the surface deformation was described by Perry (1977) for measuring fruit firmness. Near infrared reflectance has been studied in relation to measuring the internal qualities of fruit with good correlations with sugar content (Kouno *et al.* 1993a, 1993b). Correlations between sugar content of peaches and near infrared reflectance measurement have been shown (Kouno *et al.* 1993a, 1993b). NIR measurement was achieved, using a Nireco model 6500 near infrared spectrophotometer, by placing the fruit so that the light beam on the surface was at right angles to the fruit surface and covered with a black cloth to avoid the influence of external light. Four places around the equator of the fruit were selected and the NIR beam was irradiated at 2 nm intervals from 400 to 2500 nm onto the fruit and the average absorbance was measured (Kouno *et al.* 1993c).

Peaches are extremely delicate fruit when ripe and can bruise very easily. Magnetic resonance imaging has been used to obtain images of bruises on peaches to facilitate grading out damaged fruits (Chen *et al.* 1989).

Physiological Disorders

Peaches stored in 30% CO₂ at 28 °C for 42 h had high levels of ethanol compared to those stored at 8 °C (Yanez Lopez *et al.* 1998). Split pit is an internal disorder of peaches probably caused by adverse weather and too much nitrogen fertilizer. It is not possible to tell from the external appearance whether a fruit is suffering from this disorder but X-rays can be used to detect it (Bowers *et al.* 1988).

Precooling

Rapid cooling after harvest can give the fruit a stringy or woolly texture (Phillips and Armstrong 1967) and therefore it is not recommended.

Prestorage treatments

The combination of exposure to hot air at 38 °C for 12 h and then 1 µmol L⁻¹ methyl jasmonate at 20 °C

for 24 h vapour treatment reduced chilling injury and maintain fruit quality during storage at 0 °C for up to 5 weeks plus 3 days at 20 °C for shelf-life. The effects of the treatment compared to those not treated included; higher percent of extractable juice, TSS was 25.3% higher and total acid was 62.5% higher, vitamin C and total phenolic contents and higher activities of PAL, SOD and PG, and lower activities of PPO, and POD (Jin *et al.* 2009).

Treatment with 1 µl L⁻¹ 1-MCP at 20 °C for 14 h reduced the rate of softening, loss of sugars and organic acids and inhibited increases in ethylene production and respiration rate during 16 days storage in 90–95% r.h. at 8 °C for Mibaekdo and 5 °C for Hwangdo (Hee *et al.* 2009). Treating of the cultivar Jiubao with 0.2 µl L⁻¹ of 1-MCP at 22 °C for 24 h effectively slowed the decline in fruit firmness. The minimum concentration of 1-MCP that inhibited fruit softening was 0.6 µl L⁻¹ and repeated treatment resulted in more effective inhibition of ripening. Changes TSS, total sugars, TA, soluble pectin and ethylene production were also significantly reduced or delayed by 1-MCP. The activities of phenylalanine ammonialyase, polyphenoloxidase and peroxidase in the inoculated fruit were also enhanced by 1-MCP (Hongxia *et al.* 2005). In the cultivar Tardibelle treatment with 1-MCP was effective in preserving firmness during subsequent cold storage for 21 days of air but had no effect on those in CA (Ortiz and Lara 2008). Postharvest decay of the cultivar Jiubao fruit that had been inoculated with *Penicillium expansum* was reduced by treatment with 1-MCP and disease progress was reduced during cold storage for 21 days (Hongxia *et al.* 2005).

Storage

Prolonged low temperature storage can result in internal browning or a woolly texture (Haard and Salunkhe 1975). The symptoms were described as flesh browning, mealy breakdown and abnormal peeling by Kajiura (1975). At room temperature of 20 °C and 60% r.h. fruit could be kept for 1–2 days (Mercantilia 1989). Refrigerated storage recommendations include:

- –0.5 to 1 °C for 3 weeks then ripen at 18–25 °C for Hales and Elberta (Fidler 1963).

- Storage at 18.3–21.1 °C for several days until they are almost ripe then –0.6 to 0 °C and 85–90% r.h. (Phillips and Armstrong 1967).
- –0.5 to 0 °C and 85–90% r.h. for 2–3 weeks (Anonymous 1967).
- –1 to 1 °C and 85–90% r.h. for 4–8 weeks for late cultivars (Anonymous 1967).
- –0.6 to 0 °C and 90% r.h. for 2 weeks for freestone or 3–4 weeks for clingstone and some freestone (Lutz and Hardenburg 1968).
- 0 °C and 90–95% r.h. for 14 days (Mercantilia 1989).
- 2 °C for 7 days (Mercantilia 1989).
- 4 °C for 5 days (Mercantilia 1989).
- –1 to 0 °C and 90–95% r.h. for 2–6 weeks (Snowdon 1990).
- –0.5 to 0 °C and 90–95% r.h. for 2–4 weeks (Hardenburg *et al.* 1990).
- –0.5 °C with 90–95% r.h. for 14–28 days (SeaLand 1991).

Intermittent warming

Controlled atmosphere storage at –0.5 to 0 °C in 5% CO₂ and 1% O₂ plus intermittent warming to 18 °C in air for 2 days every 3–4 weeks was said to have shown promising results (Hardenburg *et al.* 1990). Intermittent warming can be used to alleviate fruit chilling injury (Xi *et al.* 2012). They stored the cultivar Jinxiu at 5 °C or at 5 °C exposed to 20 °C for 1 day every week during storage. Flesh browning was observed on the third day of shelf-life at 20 °C after 21 days at 5 °C, while no flesh browning was found in those that had been exposed to intermittent warming even for up to 28 days. Significant lower ester contents were associated with flesh browning. Alcohol acyltransferase activity increased during shelf-life of fruit exposed to intermittent warming. As precursors of esters, levels of linoleic and linolenic acids were high fruit exposed to intermittent warming.

Controlled atmosphere storage

J. E. Bernard in 1819 in France (quoted by Thompson 2010) showed that storage in zero O₂ gave fruit a life of 28 days. The cultivar Okubo was stored for 3 weeks at 1 °C in air, 3% CO₂ with 3% O₂ or 0% CO₂ with 3% O₂ by Kajiura (1975). After removal from storage, fruits were ripened at 20 °C. In cold-stored

fruits, low temperature injuries developed. In 3% O₂ with 0% CO₂, the ripening rate after storage was faster than that of fruits which had been placed in 20 °C directly after harvest. They also exhibited chilling injury. Fruits that had been stored in 3% O₂ with 3% CO₂ had a ripening rate after storage that was the same as the directly ripened fruits, and chilling injury was almost completely eliminated.

Fruits of the cultivar Springcrest were harvested at two maturity stages (flesh firmness of 60 and 45 N) and maintained at 20 °C in air (control) or for 24 or 48 h in streams of air containing either ultra low oxygen of less than 1% or high CO₂ of 30% concentration and then transferred to air for up to 8 days. The decline in flesh firmness was strongly reduced in ultra low O₂ and 30% CO₂ in fruits from both harvests; although the effect was stronger in fruits picked earlier, in which ethylene biosynthesis remained at the basal level. Ethanol increased slightly during ripening in control fruits, but ultra low O₂ and 30% CO₂ strongly stimulated ethanol production. When fruits were transferred to air, ethanol concentration declined rapidly (Bonghi *et al.* 1999). Lurie (1999) reported that controlled atmosphere storage decreased physiological disorders but did not prevent the loss of ripening ability after controlled atmosphere storage. Other storage CA storage recommendations include:

- -0.5 to 0 °C with 5% CO₂ and 1% O₂ maintained quality and retarded internal breakdown for about twice as long as those stored in air (Hardenburg *et al.* 1990).
- 0.5 °C with 90–95% r.h. with 5% CO₂ with 2% O₂ (SeaLand 1991).
- 0–5 °C with 5% CO₂ and 1–2% O₂ which had a good effect, but limited commercial use (Kader 1985).
- 0–5 °C and 3–5% CO₂ and 1–2% O₂ for both free-stone and clingstone peaches (Kader 1989, 1992).
- 10% O₂ and 10% CO₂ for the cultivars Hermoza and Somerset for up to 6 weeks (Lurie 1999).
- 0–5 °C and 85–95% r.h. with 5% CO₂ and 2% O₂ for Flavorcrest and Red Top, which reduced weight loss and postharvest decay (Eris and Akbudak 2001).

Hypobaric storage

Hypobaric storage prolonged the life of peaches from 7 to 27 days. It delayed chlorophyll and starch breakdown, carotenoid formation and the decrease in sugars and TA (Salunkhe and Wu 1973). Storage at 11–12 °C in an aerated hypobaric system at either 190 or 76 mm Hg retarded ripening compared to storage at the same temperature in air (Kondou *et al.* 1983). In the cultivar Okubo kept in hypobaric storage of 108 mm Hg, the ripening rate after storage was slower than that of fruits that had been stored in air at 760 mm Hg throughout. Mealy breakdown was reduced in hypobaric storage, but no effect was found on flesh browning or on abnormal peeling (Kajiura 1975).

Ripening

Watada *et al.* (1979) found a larger range and higher quantities of organic volatile compounds in tree ripened fruit than in those harvested before they were ripe and ripened postharvest. Bedford and Robertson (1955) showed that fruits ripened at 24 °C had a better flavour than those ripened at 29 °C. At temperatures below 18 °C rotting usually outstripped ripening. At 20 °C Wills *et al.* (2001) found that the time to ripen of the cultivars Fragar, Coronet, Loring and Flordagold increased linearly with logarithmic decrease in ethylene concentration over the range of less than 0.005, 0.01, 0.1 1.0 and 10 µL L⁻¹. In South Africa 24 °C with 1% acetylene in the atmosphere for 24 h was recommended (Fidler 1963). In Australia exposing the cultivar Victoria to 40 °C and high humidity then storage at 24 °C until ripe was recommended. To achieve this air was passed over thermostatically controlled steam heaters. In the United States immersing the fruit in water to bring its pulp temperature to 37 °C for 3–3½ min was recommended before ripening (Fidler 1963).

Disease

Postharvest diseases of fruit include brown rot (*Monilinia fructicola*), scab (*Fusicladosporium* (*Cladosporium*) *carpophilum*), grey mould (*Botrytis cinerea*) and rhizopus rot (*Rhizopus stolonifer*).

Casals *et al.* (2010a) reported that no chemical fungicide was allowed to be applied postharvest to stone fruit in Spain; therefore they evaluated radio frequency treatment at 27.12 MHz, with 17 mm distance between fruit and upper electrode and 18 min exposure time. It was found that in naturally infected fruit *Monilinia* spp. development was completely inhibited in both cultivars tested: Summer Rich and Placido by the radiofrequency treatment. Brown rot was effectively controlled by exposing fruit to 50 °C and 95–99% r.h. for 2 h. However, it did not provide protection for further *M. fructicola* infections, indicating that fruit was susceptible to subsequent infections after the treatment process and before cool storage. A 1% chitosan coating applied at 20 °C had a preventive effect against further *M. fructicola* infections on heat-treated fruit that had been previously inoculated: brown rot incidence was reduced to 10%, in comparison with the control (73%). However, chitosan applied to wounded fruit had a poor preventive effect. The antagonist, *B. subtilis* CPA-8, had a preventive effect in controlling *M. fructicola* infections: the incidence of brown rot was reduced to less than 15% for both cultivars evaluated (Baby Gold 9 and Andros), in comparison with the control fruit (higher than 98%). In contrast, when fruit were stored at 0 °C, this preventive effect was not detected (Casals *et al.* 2012). Yu *et al.* (2012a) found that the 0.5 mg L⁻¹ yeast saccharide-induced decay alleviation and defence responses of peach fruit were dependent on endogenous nitric oxide generation. Casals *et al.* (2010b) reported that postharvest curing at 50 °C and 95–99% r.h. for 2 h satisfactorily controlled brown rot on several cultivars. Different maturity levels affected curing efficacy. As fruit maturity increased, the efficacy of a postharvest curing treatment decreased from 95% control of brown rot (harvest mature fruit) to 65% (the most advanced mature fruit). The effect of *Monilinia fructicola* infection time prior to treatment also affected the curing efficacy. When the infection time was increased from 0 to 48 h, brown rot control decreased from 90 to 64%. When fruit with natural inoculum were surface sterilized prior to the curing, complete brown rot control resulted. Ozone has been shown to control fungal growth and rotting in fruit exposed to 1–2 µl

L⁻¹, but peaches were damaged by exposure to only 1 µl L⁻¹ O₃.

Pear

Rosaceae

Pyrus communis L. There are many species of *Pyrus* all of which are native to Europe or Asia. Pears were cultivated for their fruit by the Phoenicians and Romans and were a delicacy for the ancient Persian kings. There may be as many as 5000 varieties and cultivars throughout the world. There are also Asian, Chinese, Japanese and Siberian pears (*P. bertschneideri*, *P. sinensis*, *P. ussuriensis* and *P. pyrifolia*). There are hybrids between *P. communis* and *P. sinensis* called Kieffer pears that were developed for their disease resistance. Other European species include *P. amygdaliformis* that grows on the northern Mediterranean coast, *P. cordata* is a small tree that is native to Spain, Portugal and France and produces small brown fruit. *P. nivalis* and *P. salicifolia*, both of which originated in Eastern Europe, are grown as ornamentals.

They are tall vigorous trees and for commercial production are commonly grafted onto rootstocks to control their size. The fruit is a pome whose fleshy part consists of the fused base of the calyx, corolla and stamens, which may be interpreted as being the receptacle (Hulme 1971). Ripe pears will freeze at about –2.7 to –2.1 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 154. Total world production of pears in 2010 was estimated by FAO (2013) as 22,731,087 tonnes.

Harvest maturity

Cockburn and Sharples (1979) described the measurement of starch in samples of fruit to assess when to harvest (Figure 6). This method is used commercially in several countries including Turkey (Figure 7), the United Kingdom and Wawrzyńczak *et al.* (2006) used starch index in Poland (Table 5). Raffo *et al.* (2012) reported that most of the European pear cultivars fail to develop a desirable texture when ripened on the tree. They found that with Bartlett, fruit harvested 119 or 147 days after anthesis

Table 154 The composition of pear fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	83.71 g	Thiamine	0.012 mg
Energy	58 kcal	Riboflavin	0.025 mg
Protein	0.38 g	Niacin	0.157 mg
Total lipid (fat)	0.12 g	Vitamin B-6	0.028 mg
Carbohydrate, by difference	15.46 g	Folate	7 µg DFE
Total dietary fibre	3.1 g	Vitamin B-12	0.00 µg
Total sugars	9.80 g	Vitamin A	1 µg RAE
Calcium	9 mg	Vitamin A	23 IU
Iron	0.17 mg	Vitamin E	0.12 mg
		(α-tocopherol)	
Magnesium	7 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	11 mg	Vitamin D	0 IU
Potassium	119 mg	Vitamin K	4.5 µg
		(phyloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.006 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.026 g
Total ascorbic acid	4.2 mg	Fatty acids, total polyunsaturated	0.029 g

developed normal texture upon ripening while those harvested 161 days after anthesis did not ripen to a typical buttery and juicy texture. Gamrasni *et al.* (2010) evaluated different harvest dates of the cultivar Spadona and found that the later harvested fruit were larger and had superior sensory attributes. Sugar and Einhorn (2012) found that a period of conditioning may be required after harvest before pears will ripen. They concluded that d'Anjou harvested at the onset of fruit maturity could be conditioning at 5 °C for 30 days to achieve ripening capacity, while those harvested 28 days after initial maturity needed only 2 days. With conditioning at 10 °C, fruit harvested at initial maturity required approximately 18 days to achieve ripening capacity while those harvested 21 and 28 days after initial maturity ripened in less than 10 days at 10 °C, and most of the fruit from these harvest deteriorated at all durations ≥10 days at 10 °C.

1-MCP

1-MCP applied to Bartlett at 0.3 µL⁻¹ for 12 h at 20 °C immediately after harvest decreased rates of softening, ethylene production, respiration rate and yellow colour development and reduced the incidence of scald and internal breakdown

(Villalobos-Acuña *et al.* 2011). Gamrasni *et al.* (2010) showed that applying 0.2 µL⁻¹ 1-MCP for 20 h at 20 °C immediately after harvest improved quality of the cultivar Spadona after 6 months storage at -0.5 °C with 1.5% O₂ and 5% CO₂ and 2 weeks at 20 °C. Rizzolo *et al.* (2005) reported that 1-MCP prolonged or enhanced the effects of CA storage of the cultivar conference. However, they found that the effects of 1-MCP treatment at 25 and 50 nL L⁻¹ declined with duration of storage for up to 22 weeks at -0.5 °C (followed by 7 days in air at 20 °C) in both CA and air storage. Even treating the fruit again after 7 and 14 weeks storage had little additional effects on subsequent ripening. Ethylene production was lower and firmness was higher in 50 nL L⁻¹ treated fruits, while 25 nL L⁻¹ were similar to non-treated. Non-treated and 25 nL L⁻¹ treated fruit reached their best sensory quality after 14 weeks storage, while 50 nL L⁻¹ fruit reached the same sensory quality later, retaining a fresh flavour when the quality of control fruit declined and became watery or grainy. The cultivars Williams, Bosc and Packhams Triumph were stored for approximately 300 days at -0.5 °C in 2.5% O₂ + 2.0% CO₂ or in air by Lafer (2005). The fruit that had been pretreated with 625 ppb 1-MCP had delayed softening and no loss of TA in all three cultivars, whereas non-treated fruits showed excessive softening and reduction in TA during shelf life.

There are reports that treatment with 1-MCP can affect postharvest disorders. The cultivar Yali was exposed to 0, 0.01, 0.1, 0.2 or 0.5 µL L⁻¹ 1-MCP for 24 h or 0.2 µL L⁻¹ for 0, 12, 24 or 48 h and then stored at 20 °C and 85–95% r.h. by Fu *et al.* (2007). Those treated with 1-MCP retained their firmness and TSS content better than those not treated. After 100 days of storage the incidence and index of core browning was reduced by 91 and 97%, respectively, by 1-MCP treatment and the occurrence of black and withered stems was also reduced by 59% by 1-MCP after 32 days of storage. 1-MCP also reduced ethylene production and respiration rate. Rizzolo *et al.* (2005) showed that the development of superficial scald was not prevented by 1-MCP treatment, but the severity of the symptoms was less in the cultivar conference. Isidoro and Almeida (2006) reported that 1-MCP can be used to replace diphenylamine as a postharvest treatment to control scald in the cultivar Rocha, although ripening after storage was delayed by relatively high concentrations. Spotts *et al.*

(2007) reported that 1-MCP reduced the diseases of bull's-eye rot, Phacidiopycnis rot, stem end rot and grey mould in the cultivar d'Anjou. They concluded that a combination of 1-MCP and hexanal at optimal rates may reduce storage decay caused by fungal infection, control superficial scald and allow normal ripening. Lafer (2005) found that rotting caused by *Penicillium expansum* and *Botrytis cinerea* was the main problem during long-term storage and neither CA nor 1-MCP were effective in preventing fruit rotting. The effect of 1-MCP on fungal decay varied considerably among the cultivars tested and the stage of maturity.

Precooling

They are not normally precooled. However, if it is thought necessary then air cooling in a conventional cold store was the most suitable, forced-air cooling with high humidity was also suitable and hydrocooling was less suitable and vacuum cooling was unsuitable (MAFF n.d.). Porritt (1964) suggested that a delay in cooling shortened storage life and the core temperature should be reduced to near the holding temperature within 4 days.

Postharvest physiology

The fruit is classified as climacteric. Rates of ethylene production were low at harvest at less than $0.1 \mu\text{l kg}^{-1} \text{h}^{-1}$ but gradually increased during air storage at -1.1°C . After 3 months of storage in air at $-1.1^\circ\text{C} + 1$ day at 20°C , ethylene production of d'Anjou was $0.5 \mu\text{l kg}^{-1} \text{h}^{-1}$, Bosc was $30 \mu\text{l kg}^{-1} \text{h}^{-1}$ and Comice was $30 \mu\text{l kg}^{-1} \text{h}^{-1}$ (Chen 2002). Most pear cultivars exhibit climacteric-like

ethylene production during the ripening period at 20°C when optimally mature fruit have satisfied their chilling requirement of -1.1°C . The chilling requirement of optimally mature pears stored at -1.1°C for induction of normal ripening capacity was given by Chen (2002) as about 60 days for d'Anjou, 30 days for Bosc, 30 days for Comice and 15 days for Bartlett. He also gave the magnitude of ethylene production at the climacteric-like peak as $10\text{--}20 \mu\text{l kg}^{-1} \text{h}^{-1}$ for d'Anjou, $40\text{--}80 \mu\text{l kg}^{-1} \text{h}^{-1}$ for Bosc, $80\text{--}200 \mu\text{l kg}^{-1} \text{h}^{-1}$ for Bartlett and $60\text{--}80 \mu\text{l kg}^{-1} \text{h}^{-1}$ for Comice fruit. He also reported that the sensitive of unripe fruit to ethylene varied between cultivars with Bartlett the most sensitive Bosc and Comice moderately sensitive and d'Anjou least sensitive. Treatment of fruit with $100 \mu\text{l L}^{-1}$ ethylene at 20°C for 72, 48 or 24 h will initiate ripening within 3–6 days, depending on cultivar (Table 155).

Storage and controlled atmosphere storage

Predieri and Gatti (2009) tested the effects of cold storage on the consumer acceptability of the cultivar Abate Fetel. After 13 weeks of storage at -1°C they maintained their acceptable eating quality for 4–8 days and after 23 weeks acceptable eating quality was maintained for 2–6 days. Firmness differences were clearly perceived by both expert judges and consumers but did not influence the degree of liking. High scores were recorded in consumer tests conducted after 13 weeks of cold storage, but after 23 weeks a decrease in degree of liking was observed. The recommendations for storage vary considerably between cultivars, but there are general recommendations where the author does

Table 155 Respiration rates in milligram of carbon dioxide per kilogram per hour of two pear cultivars during storage at different temperatures taken from 1 to 200 days in storage (source: adapted from Chen 2002)

$^\circ\text{C}$	d'Anjou						Bartlett				
	Days in storage										
	1	25	50	100	150	200	1	10	20	90	120
-2	5.0	2.0	2.0	2.3	2.4	2.7	–	1.5	2.2	3.2	3.8
-1	5.0	2.0	2.0	2.4	2.5	2.8	–	2.2	2.4	3.6	4.2
0	5.0	2.4	2.5	3.2	4.1	4.5	–	2.5	2.6	5.6	5.9
2	5.0	3.1	3.6	5.1	–	–	–	3.2	4.5	–	–
10	9.0	6.0	7.0	–	–	–	16.0	8.1	24.0	–	–
21	17.0	7.0	7.0	–	–	–	16.0	38.0	–	–	–

not specify the cultivar. Hardenburg *et al.* (1986) recommended -0.5 to -1.5 °C with 2.0–2.5% O₂ and 0.8–1.0% CO₂. Koelet (1992) recommended 0.5 °C with 0.5–1.0% CO₂ and 2–2.2% O₂. SeaLand (1991) recommended -1.1 °C and 90–95% r.h. with 0–1% CO₂ and 2–3% O₂. Lawton (1996) recommended 0 °C and 93% r.h. with 0.5% CO₂ and 1.5% O₂. Storage at 0–5 °C with 0–1% CO₂ and 2–3% O₂ was recommended (Kader 1985) or 0–5 °C with 0–3% CO₂ and 1–3% O₂ (Kader 1992). The storage life of d'Anjou and Bartlett has been reported to be 35–40% longer at -1 °C than at 0 °C (Porritt 1964). Recommendations for specific cultivars include

Anjou (d'Anjou)

- -1.1 °C and 85–90% r.h. for 4.5–6 months (Phillips and Armstrong 1967);
- -0.5 to 0 °C and 90–95% r.h. for 4–6 months (Mercantilia 1989);
- 0.8–1% CO₂ and 2–2.5% O₂ or 0.1% CO₂ or less with 1–1.5% O₂ (Hardenburg *et al.* 1990);
- Exposure of Anjou to 12% CO₂ for 2 weeks immediately after harvest had beneficial effects on the retention of ripening capacity (Hardenburg *et al.* 1990);
- -1 °C and 90–95% r.h. for 4–6 months (Snowdon 1990);
- -1.1 °C and 90–95% r.h. for 120–180 days (SeaLand 1991).
- Chen and Varga (1997) found that no controlled atmosphere storage regime containing 0.5–2% O₂ was feasible in controlling physiological disorders of d'Anjou pears during 6 or 8 months of storage. They showed that storage in 0.5% O₂ with less than 0.1% CO₂ resulted in a high incidence of scald and black speck.
- d'Anjou developed scald during storage in air, 1.5 or 0.5% O₂ for 6 months then 2 months at 1.5% but no scald developed when fruit were stored in 0.4% O₂ that was maintained by monitoring fruit chlorophyll fluorescence. Some of the fruit stored in 0.5% O₂ developed peel black speck, a disorder previously reported on d'Anjou stored in 1% O₂ or below. All CA environments slowed peel colour change with 0.4% O₂ having a larger effect while softening was also reduced by 0.4% O₂ compared with fruit stored in air or 1.5% O₂. There was some indication that storage in 0.4% O₂ + 0.1% CO₂ may result in some fruit not softening to a commercially

acceptable value during after removal from storage (Mattheis and Rudell 2012).

Bartlett

- -1.1 °C and 85–90% r.h. for 2–3 months (Phillips and Armstrong 1967);
- -1.1 to -0.6 °C and 90–95% r.h. for 2–3 months (Anonymous 1968);
- A maximum of 5% CO₂ and a minimum of 2% O₂ (Fellows 1988);
- -0.5 to 0 °C and 90–95% r.h. for 2.5–3 months (Mercantilia 1989);
- -1 to -0.5 °C and 90–95% r.h. for 1–3 months (Snowdon 1990);
- -1.1 °C and 90–95% r.h. for 60–90 days (SeaLand 1991).

Bosc

- -1.1 to -0.6 °C and 90–95% r.h. 3–4 months (Anonymous 1968);
- -1.1 °C and 90–95% r.h. for 60–90 days (SeaLand 1991).

Buerre Bosc

- -1.1 °C and 85–90% r.h. for 3–3½ months (Phillips and Armstrong 1967);
- -1 °C and 90–95% r.h. for 3 months (Snowdon 1990).

Beurre d'Anjou

- After 6½ months' storage, at -0.5 °C the average percentage of fruits with symptoms of scald ranged from zero in fruits stored in 1% O₂ with 0% CO₂ or 1.5% O₂ with 0.5% CO₂ to 2% in fruits stored in 2.5% O₂ with 0.8% CO₂ and 100% in control fruits stored in air (Francile and Battaglia 1992).

Buerre Hardy

- -1 to -0.5 °C and 90–95% r.h. for 2–3 months (Snowdon 1990).

Clapps Favourite

- -1 to -0 °C and 90–95% r.h. for 1–2 months (Snowdon 1990).

Comice

- -1.1 °C and 85–90% r.h. for 2–3 months (Phillips and Armstrong 1967);

Table 156 Recommended controlled atmosphere storage conditions for Comice pears by country and region (source: adapted from Herregods 1993)

	°C	CO ₂	O ₂
Belgium	0 to -0.5	less than 0.8	2–2.2
France	0	5	5
Germany (Westphalia)	0	3	2
Italy	-1 to 0.5	3–5	3–4
Spain	-0.5	3	3
Switzerland	0	5	3
USA (Oregon)	-1	0.1	0.5

- -1.1 to -0.6 °C and 90–95% r.h. for 2–3 months (Anonymous 1968);
- -1 to -0.5 °C and 90–95% r.h. for 3–4 months (Snowdon 1990) (Table 156).

Concord

- -1 to -0.5 °C with less than 1% CO₂ and 2% O₂ (Johnson 1994).

Conference

- 0 °C with 2% CO₂ and 2% O₂ (Stoll 1972);
- 0.5–1 °C with 5% CO₂ and 5% O₂ (Fidler and Mann 1972);
- -1 to -0.5 °C with less than 1% CO₂ and 2% O₂ (Sharples and Stow 1986, Johnson 1994);
- -1 to -0.5 °C and 90–95% r.h. for 4–6 months (Snowdon 1990) (Table 157).

Doyenne Boussock

- -1.1 °C and 85–90% r.h. for 2 months (Phillips and Armstrong 1967).

Table 157 Recommended controlled atmosphere storage conditions for conference by country and region (source: adapted from Herregods 1993)

	°C	CO ₂ (%)	O ₂ (%)
Belgium	-0.5	<0.8	2–2.2
Denmark	-0.5 to 0	0.5	2–3
England	-1 to 5	<1	2
Germany (Saxony)	1	1.1–1.3	1.3–1.5
Germany (Westphalia)	-1 to 0	1.5–2	1.5
Holland	-1 to -0.5	≤1	3
Italy	-1 to -0.5	2–4	2–3
Italy	-1 to -1.5	1–1.5	6–7
Slovenia	0	3	3
Spain	-1	2	3.5
Switzerland	0	2	2

Doyenne du Comice

- 0.5–1 °C with 5% CO₂ and 5% O₂ (Fidler and Mann 1972).
- 0 °C with 2% CO₂ and 2% O₂ (Stoll 1972).

Flemish Beauty

- -1.1 °C and 85–90% r.h. for 2 months (Phillips and Armstrong 1967).

Hardy

- -1.1 °C and 85–90% r.h. for 2–3 months (Phillips and Armstrong 1967);
- -1.1 to -0.6 °C and 90–95% r.h. for 2–3 months (Anonymous 1968).

Josephine

- 0 °C and 90–95% r.h. for 5–6 months (Snowdon 1990).

Jules Guyot

- -1 to -0.5 °C and 90–95% r.h. for 1–3 months (Snowdon 1990).

Kieffer

- -1.1 °C and 85–90% r.h. for 2–3 months (Phillips and Armstrong 1967);
- -1.1 to -0.6 °C and 90–95% r.h. for 2–3 months (Anonymous 1968).

Packham's Triumph

- -1 °C and 90–95% r.h. for 3–6 months (Snowdon 1990) (Table 158).

Passecrassane

- -1 to 1 °C and 90–95% r.h. for 5–6 months (Snowdon 1990).

Seckel

- -1.1 to -0.6 °C and 90–95% r.h. 3–4 months (Anonymous 1968).

William's Bon Chretien

- 0.5–1 °C with 6% CO₂ and about 15% O₂ (Fidler and Mann 1972);
- 0 °C with 2% CO₂ and 2% O₂ (Stoll 1972).

Winter Cole

- -1 °C and 90–95% r.h. for 4 months (Snowdon 1990).

Table 158 Recommended controlled atmosphere storage conditions for Packham's Triumph by country and region (source: adapted from Herregods 1993)

	°C	CO ₂ (%)	O ₂ (%)
Australia (south)	-1	3	2
Australia (Victoria)	0	0.5	1
Australia (Victoria)	0	4.5	2.5
Germany (Westphalia)	-1 to 0	3	2
New Zealand	-0.5	2	2
Slovenia	0	3	3
Switzerland	0	2	2

Winter Nelis

- -1.1 °C and 85–90% r.h. for 4.5–6 months (Phillips and Armstrong 1967);
- -1.1 to -0.6 °C and 90–95% r.h. for 4–6 months (Anonymous 1968);
- -1 to -0.5 °C and 90–95% r.h. for 4–6 months (Snowdon 1990).

Wawrzyńczak *et al.* (2006) stored the cultivars Alexander Lukas, Amfora, Delbuena, Delmoip, Erica and Nojabrska at -0.5 °C with 2% O₂ and 0.8% CO₂ for 7 months followed by 4 days at 18 °C to simulate shelf life. All cultivars stored well and in general, changes in flesh firmness, TA and TSS:TA after CA storage were similar but were greatest in Delbuena and least in Amfora. CA storage conditions can affect

the quality of the fruit. It was shown that CA storage resulted in the fruit being 'liked' more than those stored in air as well as better retaining their firmness and acidity (Table 159).

Hypobaric storage

Hypobaric conditions prolonged the storage life of pears by between 1.5 and 4.5 months compared to cold storage alone. It delayed chlorophyll and starch breakdown, carotenoid formation and the decrease in sugars and TA (Salunkhe and Wu 1973).

Ripening

Ripening conditions of 20 °C (Phillips and Armstrong 1967) or 20–22.5 °C with high humidity (Anonymous 1968) were recommended. However, Wills *et al.* (1989) recommended 15–18 °C using ethylene at 10 µl L⁻¹ for 24 h in 85–90% r.h.

Diseases

White rot (*Botryosphaeria dothidea*), Black rot (*B. Obtusa*), Bitter rot (*Glomerella cingulata*), Brown rot (*Monilinia fructicola*, *M. fructigena* and *M. laxa*) and Phytophthora rot (*Phytophthora cactorum*) are fruit rots from incipient or quiescent preharvest

Table 159 Effect of controlled atmosphere storage on the acidity and firmness of Spartlett pears stored at 0 °C and their taste after 7 days of subsequent ripening at 20 °C (source: adapted from Meheriuk 1989)

Storage atmosphere		Storage time (days)	Acidity (mg 100 ml ⁻¹)	Taste 9 = like 1 = dislike	Firmness (N)
CO ₂ (%)	O ₂ (%)				
0	21	60	450b	6.1	62a
5	3	60	513a	7.6	61ab
2	2	60	478ab	7.6	60b
0	21	120	382b	4.3	55b
5	3	120	488a	6.7	58a
2	2	120	489a	6.9	58a
0	21	150	342b	2.9	51b
5	3	150	451a	7.7	58a
2	2	150	455a	7.1	58a
0	21	180	318b	–	40b
5	3	180	475a	–	62a
2	2	180	468a	–	61a

Figures followed by the same letter were not significantly different ($p = 0.05$) by the Duncan's Multiple Range Test.

infections. Postharvest diseases commonly found in pears in storage include Blue mould (*Penicillium*), Grey mould (*Botrytis cuberea* Per.), Bull's-eye rot (*Pezicula malicorticis* (H. Jacks.) Nannf.), Alternaria rot (*Alternaria alternata* (Fr.) Keissler), Mucor rot (*Mucor piriformis* E. Fischer), Side rot (*Phialophora Malorum* (Kidd & Beaumont) McColloch), Cladosporium rot (*Cladosporium herbarum* (Pers.) Link), Coprinus rot (*Coprinus psychromorbidus* Redhead & Traquair), Fisheye rot (*Butlerella eustacei* Weresub & Illman), Pink rot (*Trichothecium roseum* (Pers.) Link) and Rhizopus rot (*Rhizopus stolonifer* (Ehrenb.) Vuill.) (Snowdon 1990).

Yu *et al.* (2012b) studied the biocontrol yeast *Cryptococcus laurentii* and calcium chloride on the reduction of the blue mould decay caused by *Penicillium expansum* in pears. They found that integration of calcium chloride with chitosan at 0.5% and *C. laurentii* resulted in a more effective and stable reduction in the fungal decay compared with the treatment with either chitosan or *C. laurentii* alone. This was in spite of the observation that chitosan at 0.5% inhibited growth of *C. laurentii* both *in vitro* and *in vivo*. Sugar and Basile (2012) reported that the efficacy of postharvest fungicide treatments declined as the time between harvest and fungicide treatment increased. Calcium chloride applied to Bosc pear trees beginning in mid-July and repeated every 2 weeks for a total of three applications followed by preharvest application with fludioxonil fungicide provided the greatest decay suppression when postharvest fungicide treatments were delayed.

Physiological disorders

The effects of various factors that may influence the development of core breakdown (also called brown-heart) during storage were studied by Lammertyn *et al.* (2000). They showed some difference in susceptibility between different cultivars. Conference was more likely to develop the disorder than Doyenne du Comice. Conference fruits were particularly susceptible when stored in high CO₂ and low O₂ levels. Large fruits and late harvested fruits were also more likely to develop the disorder and it developed more during storage at 1 °C than at -1 °C. Magnetic resonance

imaging has been used to obtain images of bruises and insect damage in pears (Chen *et al.* 1989).

Pejibaye

Palmae

Bactris gasipaes HBK. synonymous with *B. speciosa* Karst., *Guilielma gasipaes* L.H. Bailey, *G. speciosa* Mart., *G. utilis* Orst.

Pejibaye was reported to be indigenous to Amazonian areas of Colombia, Ecuador, Peru and Brazil and has been cultivated and distributed by Indians from ancient times. It was introduced into Costa Rica in prehistoric times, where it is cultivated especially on the Atlantic side of that country. Every Indian dwelling has a patch of pejibaye palms. It is not as common anywhere else in Central America, although it is fairly abundant in Nicaragua, Honduras and Guatemala, and has long been grown commercially in Panama for local markets. In Colombia and Peru, great quantities of the fruits appear in the markets and vendors sell them along the streets. There are large stands of this palm in the Orinoco region of Venezuela and equatorial Brazil. The Indians of Colombia and Ecuador hold festivals when the pejibayes are in season, though in Ecuador the fruits are valued more as feed for livestock than as food for humans (Morton 1987).

Pejibaye fruits are naturally fermented by Amazonian natives to produce a thick drink called Caïçuma. A study showed that enzymatic starch hydrolysis, fermentation by *Saccharomyces cerevisiae* and filtration transformed 'caïçuma' into a highly acceptable drink with about 12.1% alcohol content and characteristic colour, clarity, pleasant flavour and 81.9% acceptability by a taste panel (Andrade *et al.* 2003). It has also been shown to be suitable for use as palm hearts because of its high stability after cutting, its slow rate of oxidation and its high acceptability by a taste panel (Joas *et al.* 2010).

It is an erect palm 20–30 m high, with a single or several slender stems up to 20 cm thick generally with stiff, black spines. The inflorescences are slender racemes 20–30 cm long on which the yellowish male and female flowers are mingled except for the

Table 160 The composition of pejubaye fruit from Honduras and Costa Rica for 100 g of ripe flesh and skin combined for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	36.4–60.9 g	Iron	0.85–2.25 mg
Protein	0.340–0.633 g	Carotene	0.290–2.760 mg
Fat	3.10–8.17 g	Thiamine	0.037–0.070 mg
Crude Fibre	0.8–1.4 g	Riboflavin	0.099–0.154 mg
Ash	0.72–1.64 g	Niacin	0.667–1.945 mg
Calcium	8.9–40.4 mg	Ascorbic acid	14.8–41.4 mg
Phosphorus	33.5–55.2 mg		

terminal few centimetre where there are only male flowers. The fruit are ovoid, oblate, cylindrical or conical, 2.5–5 cm long, cupped at the base by a green, leathery, 3-pointed calyx and are borne in clusters of up to 100 or sometimes as many as 300, weighing 11 kg or more. They are yellow to orange or scarlet, yellow and red, or brownish at first, turning purple when fully ripe. The skin is thin, the flesh yellow to light-orange, sweet, occasionally with a trace of bitterness, dry and mealy. Normally there is a single conical seed 2 cm long, with a hard, thin shell. Some fruits are seedless and there are sometimes two seeds fused together (Morton 1987). The chemical content was given by Morton (1987) in Table 160.

Harvesting and storage

The fruits may be knocked down with long poles or harvested with long poles equipped with cutters. Ladders can be used and bunches can be cut intact and lowered by rope. When the palm gets too tall they are usually cut down to obtain the fruits and the heart. Special gear of rope and stirrups has been devised to facilitate climbing (Johannessen 1966, Morton 1987). Fruits can be stored at 2–5 °C for 6 weeks with a minimum of dehydration or spoilage (Morton 1987). Fruit rot caused by *Ceratomyces paradoxa* was the most important postharvest disease in Costa Rica.

Pepino

Solanaceae

Solanum muricatum Ait. Other common names include papino, mishqui and tree melon. It is native to South America and probably originated in Peru.

The edible portion is the fruit. It has a smooth yellow skin streaked with purple and is up to 15 cm long with pale yellow flesh. It can be eaten fresh and was said to have a sweet melon flavour with a hint of lemon and pineapple (Popenoe 1992). The seeds are also said to be edible. Citric acid and approximately equal amount of malic and tartaric acids were present in all ripening stages (Huyskens-Keil *et al.* 2000).

Harvesting

Differences in maturity between clones of up to 20 days were found in the fruit growth period (Prohens and Nuez 2001), but generally harvest maturity is based on skin colour change from green to yellowish. In an experiment fruits were harvested at the mature-green, colour break and ripe stages by Huyskens-Keil *et al.* (2000). They found that fruits at the colour break stage showed a better postharvest behaviour and reduced quality losses, specifically at a storage temperature of 5 °C.

Storage

Refrigerated storage recommendations include

- 7–10 °C and 90% r.h. for 4–6 weeks (Snowdon 1990);
- 4.4 °C and 85–90% r.h. for 30 days (SeaLand 1991);
- 5 °C and 98% r.h. for up to 21 days (Ahumada and Cantwell 1996);
- 5 °C for up to 21 days (Huyskens-Keil *et al.* 2000);
- 5–10 °C and 95% r.h. for 4 weeks (Cantwell 2001).

Controlled atmosphere storage

Controlled atmospheres resulted in higher quality fruit after storage compared to storage in air and short bursts of high CO₂ concentrations improved skin firmness and colour intensity (Ahumada and Cantwell 1996).

Ripening

Glucose and fructose contents declined during ripening at 18 °C, whereas sucrose content increased significantly, leading to a higher ratio of disaccharides to monosaccharides in ripe fruits than in younger fruits. During ripening, the sugar:acid

ratio increased until the fruits reached the colour break stage, but declined thereafter, with the ratio being 16:1 and 13:1 in colour break and ripe fruits, respectively (Huyskens-Keil *et al.* 2000). Prohens and Nuez (2001) studied different clones in response to Ethephon sprays (0, 500 or 2000 mg L⁻¹). Some clones did not respond to the sprays, while in others the ripening period was shortened by more than 60%. In general, the effect of Ethephon was greater in the clones with a longer ripening period. The effects of Ethephon on fruit quality characteristics were not significant in the majority of clones, although in five clones. Ethephon resulted in skin degreening, a higher firmness and lower soluble solid content after storage compared to those not treated. On the other hand, Ethephon sprays did not affect either the postharvest behaviour or the sensitivity of fruit to bruising.

Persimmon

Ebenaceae

Diospyros kaki Thunb. Other common names include kaki, sharon fruit and date plum. They originated in Japan where they are called the food of the gods. The fruit is classified as climacteric and is green in colour as it develops and in most cultivars it turns orange or red and becomes translucent as it reaches maturity. The fruit has a pale brown calyx and contains up to eight seeds, but many modern cultivars are seedless. The chemical content was given by USDA (2012) in Table 161.

Harvesting

The soluble tannin content in the fruit varies between cultivars and in astringent cultivars it is particularly high in immature fruit (Ito 1971). It was shown that in Japan the time of harvest greatly affected tannin content and therefore astringency of the fruit (Table 162).

Grading

Diffuse reflectance measures the reflected light just below the surface of the crop. It was shown to be effective with persimmon with a diffuse reflectance of

Table 161 The composition of persimmon fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	Japanese	Native
Water (g)	80.32	64.40
Energy (kcal)	70	127
Protein (g)	0.58	0.80
Total lipid (fat) (g)	0.19	0.40
Carbohydrate, by difference (g)	18.59	33.50
Total dietary fibre (g)	3.6	–
Total sugars (g)	12.53	–
Calcium (mg)	8	27
Iron (mg)	0.15	2.50
Magnesium (mg)	9	–
Phosphorus (mg)	17	26
Sodium, Na (mg)	1	1
Potassium (mg)	161	310
Zinc (mg)	0.11	–
Total ascorbic acid (mg)	7.5	66.0
Thiamine (mg)	0.030	–
Riboflavin (mg)	0.020	–
Niacin (mg)	0.100	–
Vitamin B-6 (mg)	0.100	–
Folate (µg DFE)	8	–
Vitamin B-12 (µg)	0	0
Vitamin A (µg RAE)	81	–
Vitamin A (IU)	1627	–
Vitamin E (α-tocopherol) (mg)	0.73	–
Vitamin D (D2 + D3) (µg)	0.0	–
Vitamin D (IU)	0	–
Vitamin K (phyloquinone) (µg)	2.6	–
Fatty acids, total saturated (g)	0.020	–
Fatty acids, total monounsaturated (g)	0.037	–
Fatty acids, total polyunsaturated (g)	0.043	–

Table 162 Variations in soluble tannin content (%) of four cultivars of persimmon harvested at different times (source: adapted from Ito 1971)

Harvest date	Cultivar			
	Fuyu	Amahyakume	Aizumishirazu	Yokono
14 July	0.29	1.08	3.74	4.87
18 August	0.00	0.42	2.13	3.89
14 September	0.10	0.19	1.31	3.59
13 October	0.00	0.16	1.35	2.49
7 November	0.00	0.00	0.92	1.94

680 nm suitable for automatic grading lines (Chuma *et al.* 1980a, 1980b).

Astringency removal

Postharvest treatment with alcohol has been known for over 100 years in Japan to reduce their astringency.

Spraying fruit with 35–40% ethanol at the rate of 150–200 ml per 15 kg of fruit was shown to have removed astringency 10 days later in ambient storage. This treatment took longer to remove the astringency than CO₂ treatment, but the fruit were considered of better quality (Kitagawa and Glucina 1984). Exposure to high levels of CO₂ can be used to reduce astringency as follows:

- Exposure to 90–95% CO₂ for a short duration at 20–25 °C showed that astringency disappeared 3–4 days after removal from the CO₂ in the cultivar Hiratanenashi (Matsuo *et al.* 1976).
- Exposure to 60–90% CO₂ for 24 h at 17–20 °C removed astringency (Ben Arie and Guelfat Reich 1976).
- Exposure to 80–90% CO₂ for 24 h in a polyvinyl chloride film tent reduced astringency (Kitagawa and Glucina 1984).
- Storage at –1 °C in 4% CO₂ for about 2 weeks before removal from storage followed by 6–18 h in 90% CO₂ at 17 °C removed astringency from fruits (Hardenburg *et al.* 1990).

Fruit of the cultivar Rojo Brillante, harvested at two maturities, with and without deastringency treatment (exposure to 95–98% CO₂), were treated by high hydrostatic pressure at 200 and 400 MPa for 1, 3 or 6 min. High hydrostatic pressure caused cell wall disruption and intracellular component dispersion throughout the tissue and reduced astringency, which was attributed to precipitation of the soluble tannins that are responsible for fruit astringency. They considered that it might be possible to omit a deastringency treatment with CO₂. However, high hydrostatic pressure treatments caused an overall decrease in firmness for both harvest maturities (Vázquez-Gutiérrez *et al.* 2012).

1-MCP

Ben Arie *et al.* (2001) reported that there was very little fruit softening in storage at 1 °C in an ethylene free atmosphere and the rates of ethylene evolution and fruit softening declined with the increase in 1-MCP concentration from 0 to 600 ppb. The commercial shelf-life of the fruit was doubled or trebled following exposure to 1-MCP, the effect becoming stronger as the season advanced and the rate of softening of

non-treated fruit accelerated. No adverse effects of the treatment were observed. Black spot (*Alternaria alternata*) was the limiting factor in storage, but 1-MCP had no observable effects on infection levels. Kaynaş *et al.* (2009) reported that the cultivar Fuyu treated with 1-MCP at either 625 or 1250 ppb for 24 h at 18–20 °C and then storage in sealed LDPE bags at 0–1 °C and 85–90% r.h. could be kept for 120 days. Fuyu stored by Pinto *et al.* (2007) at 10 °C, especially in 1% O₂ + 0% CO₂ and 2% O₂ + 0% CO₂ plus 1-MCP, had a higher percentage of firm fruits and lower decay incidence after 17 days. The cultivar Nathanzy was harvested when the orange colour had developed on the peel (commercial maturity) by Ramm (2008) and then treated with 1-MCP at 0.5, 1 or 1.5 µl L⁻¹ for 24 h at 20 °C and stored at 20 °C. The non-treated fruit softened within 15 days but those treated with 1-MCP at 1 or 1.5 µl L⁻¹ remained firmer for 30 days after harvest and had lower respiration rates, but 0.5 µl L⁻¹ had a limited inhibitory effect on softening. Changes in total soluble solid, acidity and peel colour occurred during storage, but all were significantly delayed by 1-MCP. It was concluded that 1-MCP is effective for quality maintenance and extension of shelf life in persimmon and could allow harvesting at the orange stage of maturity, at which stage the most desirable organoleptic attributes had been developed on tree. Luo (2007) treated the cultivar Qiandaowuhe with 3 µl L⁻¹ 1-MCP for 6 h and stored them at 20 °C, which greatly extend their postharvest life, compared to those not treated. 1-MCP treatment delayed the onset of ethylene production and the respiration rate and delayed the depolymerization of chelator-soluble pectic substances and alkali-soluble pectic substances. These are cell wall hydrolysis enzymes, and the increase in water-soluble pectic substances was reduced compared to non-treated fruit. Nakatsuka *et al.* (2012) used solid CO₂ (dry ice) for astringency removal in the cultivar Saijo. After dry ice treatment fruit softened completely, but fruit firmness was maintained in fruit that had been pretreated with 1-MCP.

Besada *et al.* (2008) reported that gibberellic acid applied to fruit of the cultivar Rojo Brillante prior to harvesting combined with 1-MCP applied postharvest delayed the symptoms of chilling injury and extended their storage at 1 °C for almost 3 months.

Postharvest physiology

Besada *et al.* (2010) found that Fuyu fruit were sensitive to exposure to ethylene. Even at $0.2 \mu\text{L L}^{-1}$ for 1 day at 20°C fruit showed accelerated softening and colour change.

Storage

At room temperature of 20°C and 60% r.h. they could be kept for 5–6 days (Mercantilia 1989) and Besada *et al.* (2008) found that storage of the cultivar Rojo Brillante at either 1 and 15°C retained their commercial quality for 20 days. Besada *et al.* (2008) found that storage of the cultivar Rojo Brillante at either 1 and 15°C retained their commercial quality for 20 days.

Refrigerated storage recommendations include

- -1.1°C for 2 months with 8 days subsequent shelf life (Wardlaw 1937);
- 0°C and 85% r.h. for 120 days in Australia (Wardlaw 1937);
- -1°C and 90% r.h. for 3–4 months (Lutz and Hardenburg 1968);
- $0-1.7^\circ\text{C}$ and 85–90% r.h. for 7 weeks (Pantastico 1975);
- 0°C for about 2 months for Fuyu with an increase in colour intensity and some softening especially where ethylene is present (Kitagawa and Glucina 1984);
- 0°C and 90% r.h. for 2–3 months (Mercantilia 1989);
- -1 to 0°C and 90–95% r.h. for 2–4 months (Snowdon 1990);
- 10°C and 90–95% r.h. for 35–84 days for Fuyu (SeaLand 1991);
- 5°C and 90–95% r.h. for 50–90 days for Hachiya (SeaLand 1991).

Controlled atmosphere storage

CA recommendations include

- 1°C and 90–100% r.h. with 8% CO_2 and 3–5% O_2 for Fuyu (Hulme 1971);
- 0°C with 5–8% CO_2 and 2–3% O_2 for 5–6 months for Fuyu (Kitagawa and Glucina 1984);
- $0-5^\circ\text{C}$ with 5–8% CO_2 and 3–5% O_2 was reported to have only a fair effect on storage but not used commercially (Kader 1985, 1992);

- 5°C and 5–8% CO_2 with 3–5% O_2 SeaLand (1991);
- -0.5°C with 15% O_2 with 15% CO_2 maintained the highest flesh firmness of Fuyu after 100 days of storage and 4 days' shelf life at 14°C (Brackmann *et al.* 1999a).

Modified atmosphere packaging

In Korea fruits are stored commercially for 6 months at $2-3^\circ\text{C}$ with minimal rotting or colour change, and storage in the same conditions with 10 fruits sealed in 60- μ thick PE film bags was even better (Thompson 1974, unpublished). A problem of condensation on the inner surface of the bags was overcome by cooling the fruit before packaging. In an experiment in Brazil fruits were stored in 40- μ -micro-perforated PE film, with or without ethylene absorption (sachets of potassium permanganate inside the packaging) and with or without postharvest dipping in iprodione ($150 \text{ g } 100 \text{ L}^{-1} \text{ a.i.}$). On average the levels of gases inside the packaging was 11.5% for O_2 and 6.7% for CO_2 . Ethylene absorption reduced skin browning but did not affect flesh firmness. Iprodione treatment not only reduced decay from 69 to 47% but also caused skin browning (Brackmann *et al.* 1999a). Lower sensitivity to ethylene was observed when Fuyu fruit were stored at 0°C in MA packaging after ethylene exposure at 20°C , where fruit quality was not affected by exposures of 1 day at $\leq 1 \mu\text{L L}^{-1}$, and only slightly by 2 days at less than $0.5 \mu\text{L L}^{-1}$ ethylene. When ethylene exposure was carried out at 0°C after sealing fruit in MA bags, fruit showed the lowest sensitivity to ethylene, with only a slight decrease of firmness with ethylene exposure at the end of the storage period, and no significant effect on exposure at the beginning of the storage period (Besada *et al.* 2010).

Ripening

Fruits held at 18.3°C in an atmosphere containing $1000 \mu\text{L L}^{-1}$ ethylene for 50 h or $500 \mu\text{L L}^{-1}$ ethylene for 60 h softened more quickly and had lower astringency levels than fruit ripened in air (Ito 1971). Ripening at $18-21^\circ\text{C}$ using ethylene at $10 \mu\text{L L}^{-1}$ for 24 h in 85–90% r.h. was recommended by Wills *et al.* (1989).

Postharvest physiology

Results showed that the cultivar Qiandaowuhe displayed a typical climacteric pattern of respiration and ethylene production. Peak CO₂ production and ethylene production were observed on the fourth day. Fruit softening was accompanied by a progressive increase in water-soluble pectic substances and a progressive decrease in chelator-soluble pectic substances and alkali-soluble pectic substances. The activities of pectinmethylesterase and polygalacturonase started increasing sharply and reached a maximal value on days 4 and 6, respectively, and then decreased slowly. 1-MCP treatment delayed the onset of climacteric ethylene production and respiration in persimmon fruit and also significantly retarded the activities of pectinmethylesterase and polygalacturonase during ripening at 20 °C. Consistent with the activity trends of cell wall hydrolysis enzymes, 1-MCP treatment also delayed the depolymerization of chelator-soluble pectic substances and alkali-soluble pectic substances and reduced the increase of water-soluble pectic substances compared with the control fruit. Thus, application of 1-MCP can greatly extend the postharvest life of the cultivar Qiandaowuhe persimmon fruit (Luo 2007).

Diseases

Kobiler *et al.* (2011) reported that in Israel, black spot caused by *Alternaria alternata* is the main postharvest factor that impairs the quality and reduces the storability of the cultivar Triumph. The fungus infects the fruit in the orchard and remains quiescent until harvest. After harvest, the pathogen slowly colonizes the fruit during storage at 0 °C, which elicits black spot symptom development 2–3 months after storage entry. A commercial postharvest dip in at 500 mg L⁻¹ chlorine released from sodium troclosene tablets, effectively controlled black spot in fruit stored for up to 2 months, but decay incidence increased 2½ months of storage. Preharvest treatments treated with a single spray with the curative fungicide polyoxin B 14 days before harvest in combination with the postharvest chlorine dip treatment, the black spot infected area was reduced by 60%, compared with the chlorine dip alone. At the postharvest stage poststorage on-line spraying with sodium troclosene, applied in combination with the postharvest chlorine dip, improved the percentage of marketable fruit by 10%, compared with the chlorine dip alone.

Physalis

Solanaceae

Physalis peruviana L. Other common names include Cape gooseberries, goldenberry and Peruvian cherry. Its origin is the Andean mountains of Peru, Colombia and Ecuador where the fruits grow wild. Recently it has become an important crop and has been widely introduced into cultivation in other tropical, subtropical and even temperate areas. It may have been cultivated in England since the late 18th century and in South Africa before 1807 and soon after in Australia, New Zealand and some Pacific islands. It is a weak-stemmed shrub about 1–2 m tall. The fruit is a berry that is yellow when mature and is globular in shape and up to 2 cm in diameter. The fruit is enclosed in a brown bladder-like calyx (Purse-glove 1968). Citric acid was the most prevalent organic acid, followed by malic acid, ascorbic acid, tartaric acid and oxalic acid and the prevailing sugars were sucrose, followed by glucose and fructose. Fruit harvested at maturity grade 4 (yellowish-green colour) with calyx drying at 24 °C and those at grade 5 dried at 18 °C best conserved sucrose concentration (Novoa *et al.* 2006).

Harvesting

Optimum storage was when fruits were harvested at the maturity stage with green pedicels (Lizana and Espina 1991). Fruits were harvested by Sarkar *et al.* (1993) 45 days (mature-green), 50 days (ripening) or 55 days (fully-ripe) postanthesis. They found that the mature-green fruits retained much more acidity during storage, while ripening fruits retained appreciable amounts of ascorbic acid during storage. For long-term storage they found that fruits should be harvested at the ripening stage.

1-MCP

Valdenegro *et al.* (2012) reported that treatment with 1-MCP at 0.2 µl L⁻¹ prior to storage significantly preserved their antioxidant capacity, vitamin C and polyphenol content compared to fruit that had not been treated. Gutierrez *et al.* (2008) reported that fruits treated with 5 µl L⁻¹ 1-MCP had a higher respiration rate during storage at 25 °C than those not treated but the onset of the ethylene climacteric in immature green and mature green fruit.

Postharvest physiology

Valdenegro *et al.* (2012) reported that it was a climacteric fruit and its ripening is regulated by ethylene and during ripening the ethylene production, respiration rates and the TSS:acid ratio increased constantly. They also found that antioxidant capacity was rapidly reduced during storage at 20 °C and ethylene treatment (2000 µl L⁻¹ Ethrel) increased this reduction. Novoa *et al.* (2006) also reported that it was a climacteric fruit and in storage at 12 °C the peak climacteric was 12 days after storage had begun.

Storage

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be 1–2 weeks (Mercantilia 1989). Refrigerated storage recommendations include

- 14 °C and 80% r.h. for 1–2 months (Mercantilia 1989);
- 14 °C and 80% r.h. (Snowdon 1990);
- 4 °C and 90–95% r.h. for 72 days for fruits with the calyx attached (Fischer *et al.* 1990);
- 12.2 °C and 80% r.h. (SeaLand 1991);
- 0 °C for 33 days before keeping them at 7 days at 18 °C (Lizana and Espina 1991).

Diseases

Fungal infection by *Alternaria*, *Botrytis*, *Cladosporium* and *Penicillium* spp. occurred in storage especially at 7 °C (Lizana and Espina 1991). *Botrytis cinerea* attacked fruit whose calyx had been dried at 18 °C while storage at 24 °C for calyx drying was the most efficient compared to fruit with calyx drying at 18 °C (Novoa *et al.* 2006). 1-MCP application at either 0.5 or 5 µl L⁻¹ did not prevent decay in fruit harvested at the orange maturity stage but reduced its incidence (Gutierrez *et al.* 2008).

Pineapple

Bromeliaceae

Ananas comosus (L.) Merrill synonymous with *A. sativus* Schult. f., *Ananassa sativa* Lindl., *Bromelia ananas* L., *B. comosa* L. Other common names include pina and abacaxi. It is believed to have originated in the region of south eastern Brazil,



Figure 111 Transport and marketing of pineapples in Uganda in July 2009. See colour plate section.

northern Argentina and Paraguay and was developed and domesticated by the indigenous Indians in tropical America in prehistoric times. It was taken to Central America and the Caribbean Islands in pre-Colombian times. It is a parthenocarpic multiple fruit called a syncarp or sorosis, which is composed of some 100–200 berry-like fruitlets, sometimes called the eyes, attached to a central peduncle. The skin or peel is often referred to as the *shell* (Figure 111).

The proteolytic enzyme bromelain is extracted from pineapples with its highest concentration in the stems and to a lesser extent in the fruit. Bromelain is used in the pharmaceutical and food industries including tenderizing meat and chill-proofing beer. It is added to gelatin to increase its solubility for drinking. The main producers are Japan and Taiwan where it was formerly extracted from pineapple fruit or juice but now it is more frequently extracted from the plant stems when fields are being cleared for replanting. In Sri Lanka the mean ascorbic acid level were 18.8 mg 100 g⁻¹ in fruit stored at 10 °C for 21 days followed by 48 h at 28 ± 2 °C compared with 9.3 mg 100 g⁻¹ in fruit stored at 28 ± 2 °C for 6 days (Wilson Wijeratnam *et al.* 2005). Othman (2011) analysed Mbezi pineapples in Tanzania and found moisture content 68–89%, crude fat 0.12%, crude fibre 0.40% and ash 0.20%. The chemical content was given by USDA (2012) in Table 163 and by Morton (1987) in Table 164.

TA was 0.80–1.50% (Othman 2011) for the Mbezi, 0.7% for Mauritius, 0.6% for Kew in Sri Lanka

Table 163 The composition of pineapple fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.00 g	Thiamine	0.079 mg
Energy	50 kcal	Riboflavin	0.032 mg
Protein	0.54 g	Niacin	0.500 mg
Total lipid (fat)	0.12 g	Vitamin B-6	0.112 mg
Carbohydrate, by difference	13.12 g	Folate	18 µg DFE
Total dietary fibre	1.4 g	Vitamin B-12	0.00 µg
Total sugars	9.85 g	Vitamin A	3 µg RAE
Calcium	13 mg	Vitamin A	58 IU
Iron	0.29 mg	Vitamin E	0.02 mg
		(α-tocopherol)	
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	8 mg	Vitamin D	0 IU
Potassium	109 mg	Vitamin K	0.7 µg
		(phyloquinone)	
Sodium	1 mg	Fatty acids, total saturated	0.009 g
Zinc	0.12 mg	Fatty acids, total monounsaturated	0.013 g
Total ascorbic acid	47.8 mg	Fatty acids, total polyunsaturated	0.040 g

Table 164 The composition of ripe pineapple from Central America for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	81.3–91.2 g	Phosphorus	6.6–11.9 mg
Ether extract	0.03–0.29 g	Iron	0.27–1.05 mg
Crude fibre	0.3–0.6 g	Carotene	0.003–0.055 mg
Nitrogen	0.038–0.098 g	Thiamine	0.048–0.138 mg
Ash	0.21–0.49 g	Riboflavin	0.011–0.04 mg
Calcium	6.2–37.2 mg	Niacin	0.13–0.267 mg
		Ascorbic acid	27.0–165.2 mg

(Weerahewa and Adikaram 2005) and 0.51% for Smooth Cayenne in Brazil (Antunes *et al.* 2008a, 2008b). Othman (2011) and Dhar *et al.* (2008) both reported decreases in TA in pineapples during storage. The reduction of TA might also be due to the utilization of acids for respiration.

TSS was 15.2% for Mauritius (Weerahewa and Adikaram 2005), 12.8% for Malaysian Josapine (Shamsudin *et al.* 2007), 13.5% Brazilian Cayenne (Antunes *et al.* 2008a, 2008b) and 15.7–29.3% (Othman 2011). The total sugars content of Mbezi was 15.2% (Othman 2011), Malaysian Josapine was 13.6% (Shamsudin *et al.* 2007) Cayenne from Brazil was 13.2% and Pearl from Brazil was 14.5% (Antunes *et al.* 2008a, 2008b) and 9.85% (USDA

2011). Reducing sugars content in Mbezi pineapples was 14.2% (Othman 2011), 13.8% for Nigerian sweet Cayenne (Achinewhu and Hart 1994) and only 2.9% reported for pineapples from Ghana by Asare-Bediako *et al.* (2007).

Ascorbic acid content was given on a fresh weight basis as 27.0–165.2 mg 100 g⁻¹ (Morton 1987), 22.5–33.5 mg 100 g⁻¹ (Achinewhu and Hart 1994), 47.8 mg 100 g⁻¹ (USDA 2011) and 7.9–33.4 mg 100 g⁻¹ (Othman 2011). Othman (2011) reported that the ascorbic acid content of freshly harvested fruits was 27.4 mg 100 g⁻¹ in early season fruits and 33.4 mg 100 g⁻¹ in late season fruits. Dhar *et al.* (2008) and Othman (2011) both showed that the ascorbic acid content decreased significantly during the storage.

Preharvest ethylene treatment

Morton (1987) reported that in 1874 in the Azores it was accidentally discovered that smoke would bring pineapple plants into bloom in 6 weeks and in 1936 acetylene was employed to expedite uniform blooming. Some growers deposited calcium carbide in the crown of each plant that released acetylene when it got wet. Other chemicals that have been used include α-naphthaleneacetic acid, β-naphthylacetic acid and β-hydroxyethyl hydrazine. Ethrel (Ethephon) has been used as a source of ethylene for decades to initiate flowering. Chemical treatment is given when the plants have reached the 30-leaf stage, which is when they are about 6 months old or 3 months before their natural flowering time depending on the cultivar. Ethrel has also been applied just before harvesting to accelerate degreening and therefore the development of the orange colour in the skin. In Queensland Smooth Cayenne pineapples treated prior to harvest with Ethrel, at a concentration of 2½ L in 1000 L of water had superior eating quality, degreened more evenly, but had a shorter shelf life than fruit that had not been treated because of accelerated skin senescence. Treated fruit left on the plant for 23 days had inferior eating quality than the untreated fruit 10 days after harvest (Smith 1991). These effects are probably due to the effect of the ethylene speeding up the maturation of the fruit. Postharvest treatment with Ethrel can result in rapid uniform skin degreening but their shelf life may be slightly shorter

and it is not approved for postharvest use (Paull 1997).

Harvesting

Harvest maturity is usually based on skin colour and the shape of the individual fruitlets. Colour is not an infallible means of measurement since, for example, Smooth Cayenne grown in Ghana can be fully mature with yellow sweet flesh while the skin is still green. This has presented a problem in marketing such fruits in Europe and in some cases they have been labelled to indicate that they are ripe while the skin is green. Skin colour can vary due to season, rainfall, microclimate and field practices. In other cases estimation of the skin colour can be effective. The eyes turn from green to yellow orange from the bottom and maturity can be judged on the number of rows of eyes that have changed colour. A common harvest maturity is when 2 or 3 rows have changed colour. In Hawai'i skin colour is supplemented by a minimum reading of 12 °Brix for fruit destined for fresh consumption (Bartholomew and Paull 1984).

Harvest maturity can also be estimated by relating it to the time after flowering or mid-flowering but the number of days may vary from place to place. Bartholomew and Paull (1984) mentioned that in Madagascar the period from flower induction to ripening varied from 140 to 221 days and in South Africa from 234 to 283 days. For Smooth Cayenne in Hawai'i Dull (1971) reported that it took 110 days from the completion of flowering to harvest maturity but Bartholomew and Paull (1984) found that it was between 70 and 120 days, that is from mid-flowering to the onset of ripening. These variations were attributed to seasonal temperature variation.

In Queensland in winter pineapples are harvested at an immature stage to avoid black heart, and this stage is preferable for handling because of high resistance to bruising (Smith 1983a, 1983b). Half ripe (50% of the shell yellowing) Smooth Cayenne fruit can be held for about 2 weeks at 7.5 °C and still have about 1 week of shelf life (Paull 1993) and at this stage the fruit was suitable for export (Salunkhe and Desai 1984). Quarter yellow (25% yellowing) pineapples at harvest gain about one additional week's storage for every 6 °C decrease in storage temperature (no temperature

range was reported) and at 7 °C the maximum storage life was 4 weeks (Dull 1971).

Postharvest handling should be with care so as not to damage the fruit. However some fruit are merely stacked in lorries and thrown about, which probably does not matter too much as in the case of pineapples and oranges. In these two cases the fruit would be processed within a few hours of harvesting. The sound of a fruit as it is tapped sharply with the knuckle of the finger can change during maturation and ripening and consumers sometimes use the method of testing fruit. This method may only be used postharvest to determine their maturity since the leaves are so spiky that it would be very difficult to get at the fruit.

Prestorage treatments

Shinjiro *et al.* (2002) found that the rate of colour change of immature, mature green or ripe fruits was slower for those that had been treated with 1-MCP. The delaying effect was greater in the immature fruit. They also showed that 1-MCP treatment several times during storage actually resulted in temporary stimulation of ethylene production immediately after each treatment, but 1-MCP decreased their respiration rate. Wijeratnam *et al.* (2006) reported that treatment with chitosan alleviated chilling injury and black rot disease and retained superior quality compared with untreated fruits after cold storage. Hu *et al.* (2011) treated fruits of the cultivar Paris with Sta-Fresh 2952 (FMC) and Sta-Fresh 7055 (FMC) wax solutions at various concentrations between 30 and 120 g L⁻¹. After being air dried, the samples were placed in 0.04-mm-thick polyethylene bags and stored at 7 °C and 90% r.h. for 21 days and transferred to 25 °C for 3 days to simulate shelf conditions. Sta-Fresh 2952 wax at 60 g L⁻¹ was more effective in alleviating chilling injury and also delayed the changes in firmness, flesh colour, weight loss and soluble protein content. It also decreased TA, TSS, cell membrane permeability, malondialdehyde and ascorbic acid when compared with those in control.

Postharvest physiology

It is non-climacteric and its ethylene production rate is low at about 0.1–1.0 µl kg⁻¹ h⁻¹. Their respiration rates were given in Table 165.

Table 165 Respiration rate of pineapple fruit at different temperatures (source: adapted from Paull 1997)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
5	2
10	4–7
15	10–16
20	19–29

Chilling injury

Mature pineapples will freeze at about -1.3 to -1.0 °C (Wright 1942) but they are very susceptible to chilling injury when stored at temperature below 10 °C (Dull 1971). Rohrbach and Paull (1982) reported that immature fruit should not be shipped because they were prone to chilling injury. Chilling injury occurred in Smooth Cayenne in storage below 7 °C (Akamine *et al.* 1975). Dull (1971) reported that at 8 °C Smooth Cayenne could be stored for 1 week without chilling injury. The characteristics of chilling injury in Smooth Cayenne as described by Dull (1971) were failure of the green shell colour to turn to yellow, the yellow shell fruit turning brown or a dull colour, shrivelling of the shell and drying and wilting and discoloration of crown tip. At low temperature the fruit's skin darkens in severe cases of injury (Paull 1993). The breaking up of internal tissue gives a watery appearance. The watery appearance is the advanced stage of the watery spots appearing at the base of fruitlets. Dull (1971) found that the symptoms developed when fruit was stored at temperatures within the range 18–30 °C after storage below 7 °C. The crown is more susceptible to low-temperature injury than the fruit itself (Paull and Rohrbach 1985) and for European markets a well-developed crown is required. Crown leaves that turn brown at the edge or become limp, detracts from the appearance of the fruit and usually reduces its market value. The effect of low-temperature storage on shell appearance and the crown was said to be due to a loss of water. The crown is the site of most of the fruit's initial weight loss having stomata that appear to be open with no diurnal cycling (Paull 1993).

Storage

In a study in South Africa the most suitable storage temperature for Queen (harvested at 50–80%

yellow and less than 10% sugar content) was 14 °C, with no chilling injury occurring in storage at about 12 °C. However, some internal browning was noted after storage at all temperatures between 10 and 20 °C (Swarts 1991). In subsequent work it was found that internal browning was associated with prestorage stress and was not a problem with initially sound fruit (Swarts 1991). Queen pineapples stored at 2 or 4 °C developed a white watery pulp while fruit stored at higher temperatures developed internal browning (Van Lelyveld *et al.* 1991). Storage at 3 and 8 °C for longer than 2 weeks resulted in the crown and shell appearance being unacceptable (Paull and Rohrbach 1985). At room temperature of 20 °C and 60% r.h. they could be kept for only about 3 days (Mercantilia 1989). Refrigerated storage recommendations include

- 10 °C and 90% r.h. for 2–4 weeks for green fruit (Anonymous 1967);
- 4.5–7 °C and 90% r.h. for 2–4 weeks for ripe fruit (Anonymous 1967);
- 8.6 °C in South Africa (Hulme 1971);
- 8 °C Smooth Cayenne could be stored for 1 week without chilling injury (Dull 1971);
- 7 °C with a maximum storage period of 4 weeks (Akamine *et al.* 1975);
- 7 °C for at least 7 days (Smith 1983a, 1983b);
- 8.3–10 °C and 85–90% r.h. for 4–6 weeks with 4% loss for all green fruit (Pantastico 1975);
- 14.4–6.7 °C and 85–90% r.h. for 1–2 weeks for 25% yellow fruit (Pantastico 1975);
- 10 °C and 90–95% r.h. for 2–3 weeks for unripe fruit (Mercantilia 1989);
- 7–8 °C and 90–95% r.h. for 5–7 days for ripe fruit (Mercantilia 1989);
- 10–13 °C and 90% r.h. for 3–4 weeks for mature green fruit (Snowdon 1990);
- 7–10 °C and 90% r.h. for 3–4 weeks for turning fruit (Snowdon 1990);
- 7 °C and 90% r.h. for 2–4 weeks for ripe fruit (Snowdon 1990);
- 10 °C and 85–90% r.h. for 14–36 days (SeaLand 1991);
- 8 or 12 °C for less than 3 weeks (Haruenkit and Thompson 1993).

Controlled atmosphere storage

CA storage recommendations include

- 7.2 °C with 2% O₂ for Smooth Cayenne (Akamine and Goo 1971);
- 10–15 °C with 5% O₂ and 10% CO₂ at (Kader 1985);
- 8 °C with either 3% O₂ and 5% CO₂ or 3% O₂ and 0% CO₂ for Smooth Cayenne, but it did not suppress the internal browning symptoms (Paull and Rohrbach 1985);
- 22 °C with 3% O₂ in the first week of storage followed by 8 °C effectively reduced internal browning symptoms (Paull and Rohrbach 1985);
- 10–15 °C with 10% CO₂ and 5% O₂ had a fair effect but was not being used commercially (Kader 1985);
- 8–13 °C with 5–10% CO₂ and 2–5% O₂ (Kader 1989, 1992);
- 10 °C with 10% CO₂ with 5% O₂ (SeaLand 1991);
- 7–13 °C and 85–90% r.h. with 2–5% O₂ and 5–10% CO₂ for 2–4 weeks (Burden 1997).

Hypobaric storage

Staby (1976) stated that storage of pineapple under hypobaric condition can extend the storage life for up to 30–40 days.

Packing and transport

Pineapples will only fit into boxes in small numbers of around four or six packed vertically or horizontally with a crown of leaves cut to fit snugly into the box. For transportation by sea freight the storage temperature of 7–8 °C for ripe and 10 °C for unripe fruit has been recommended (Anonymous 1989).

Diseases

Black rot caused by *Chalara paradoxa* (de Seynes) Sacc. = *Thielaviopsis paradoxa* (de Seynes) Höhn. (teleomorph: *Ceratocystis paradoxa* (Dade) C. Moreau). Infection produces internal soft decay that is water soaked and dark yellow turning black with black spores. The fungus survives in plant debris in the field that produce conidia that land on the fruit by rain splashes and infect them through insect damage and growth crack and between the natural gaps between the syncarps.

Phytophthora heart rot caused by *Phytophthora cinnamomi* Rands *P. nicotianae* Breda de Haan var. *parasitica* (Dastur) G.M. Waterhouse = *P. parasitica* Dastur. The fungus infects the roots and can cause the plant to lodge. Developing fruit that are in contact with the soil may be infected. Symptoms are an initial water-soaked rot that develops behind the individual syncarps but with no external symptoms. Infected fruit may be harvested and infections are not observed until they reach the market.

Aspergillus rot caused by *Aspergillus flavus* Link:Fr. and other *Aspergillus* spp. that can cause black mould inside flower cavities or even dry rot.

Botryodiplodia rot caused by *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl. = *Botryodiplodia theobromae* Pat. It is a wound parasite that usually infects through the cut pedicel and spreads up the central axis of the fruit and the flesh giving it a water-soaked dark brown symptom. Minute black pycnidia eventually develop on the peel. The disease developed rapidly at 25 °C but was held in check in storage below 10 °C (Tandon and Bhargava 1962).

Interfruitlet corking, leathery pocket, fruitlet core rot caused by *Penicillium funiculosum* Thom. Infections by *P. funiculosum* that begin on the floret before the flower opens can cause inter-fruitlet corking, leathery pocket, and fruitlet core rot. Symptoms include light or dark brown soft rots in the centre of the syncarps or the diseased tissue may become almost black and be wet or dry depending on the surrounding humidity.

Rhizopus rot caused by *Rhizopus oryzae* Went & Prinsen Geerligs *R. stolonifer* (Ehrenb.:Fr.) Vuill. Infected fruit become soft and covered with fungal mycelium and spreads rapidly at tropical temperatures (Snowdon 1990).

Yeast fermentation. As with other fruit pineapples contain many yeasts, including *Saccharomyces*, and bacteria. In damaged and overripe fruit and between the natural gaps between the syncarps, existing yeasts may start to grow or new yeasts may invade and cause fermentation with bubbles of gas and juice escaping through cracks in the skin. The skin eventually turns brown and leathery and the internal flesh becomes spongy with a bright yellow flesh.

Bacterial heart rot caused by *Erwinia chrysanthemi* Burkholder *et al.* Infection is at flowering but symptoms occur as the fruit begins to ripen as a soft rot

that can develop before or after harvest and eventually can cause complete collapse of the fruit within a few days.

Pink and marbling diseases. Infections by bacterial complexes, including *Acetobacter* and *Enterobacter*, begin after the flower opens that can result in various symptoms including pink disease and marbling disease.

Fruitlet core rot caused by the fungi *Penicillium funiculosum*, *Fusarium moniliforme* var. *subglutinans*, the round yeast *Candida guilliermondii*, the fruit mite *Steneotarsonemus* sp. and the red mite *Dolichotetranychus floridanus*. This disease complex is also called black spot or fruitlet brown rot. Symptoms appear as brown to black coloured areas in the centre part of individual syncarps. It is more serious in low-acid cultivars and some control can be achieved by spraying the crop with an acaricide to control the mites that spread the disease.

Infection of the fruit is commonly through the cut fruit stalk. Dipping this area directly after it has been cut is normally sufficient to control postharvest disease. This allows for reduced levels of fungicide application that may thus leave a lower residue and costs less in chemical used. Reyes *et al.* (2004) reported that epiphytic antagonistic microorganisms were present on the pineapple fruit that could inhibit *Chalara paradoxa* growth *in vitro*. The most inhibitory isolated was *Pichia guilliermondii*. A mixture of five selected yeast isolates halved black rot severity compared to the control and the application of *P. guilliermondii* and was comparable with storage at 8–10 °C. Combining *P. guilliermondii* or the yeast mixture with a half rate of fungicide resulted in complete control of black rot comparable to control achieved with a commercial rate of recommended fungicide. A recommended vapour heat treatment was 43 °C in saturated air for 8 h and then holding the temperature for a further 6 h (Jacobi *et al.* 1993). Wilson Wijeratnam *et al.* (2005) inoculated pineapples with 104 spores ml⁻¹ of *Chalara paradoxa*. Fruit that had been then treated by immersion in water at 54 °C for 3 min were free of disease when stored at 10 °C for 21 days followed by 48 h at an ambient temperature of 28 ± 2 °C. Symptoms of the disease were observed in fruit that were inoculated and stored under the same conditions, but with no hot water dip. Colour of fruit, ascorbic acid levels and TA were not affected by the hot water dip.

Physiological disorders

Internal browning, also known as blackheart, is a major storage disorder, often associated with chilling injury. In Australia when the night temperature fell below 21 °C while the plant was growing resulted in postharvest internal browning of the fruit (Smith and Glennie 1987). Soares *et al.* (2005) reported that application of potassium fertiliser as the plants were growing reduced internal browning in fruit harvested at colour break or half ripe. The maximum response was achieved with 16 g of K₂O per plant. Selvarajah *et al.* (2001) found that treatment with 0.1 ppm (4.5 nmol L⁻¹) 1-MCP for 18 h at 20 °C effectively controlled internal browning during subsequent storage at 10 °C for 4 weeks. These results suggest that ethylene may be involved in the internal browning. Self *et al.* (1993) have shown that there was a relationship between ultrasonic velocity and the internal browning in pineapples so that this technique may be used to detect its presence.

Translucence of pineapple has been related to high nitrogen as well as high radiation, temperatures and rainfall during growth. The symptom is water-soaked areas where the air spaces between the cells are filled with liquid and the fruit have a flat taste and even off flavours. It commonly occurs before harvest and increases postharvest. It is more common in large fruit, which suggests that it is related to fruit growth rates and water and carbohydrate supply. Affected fruit are fragile and susceptible to damage, disease and sunburn (Paull and Reyes 1996).

Pitanga

Myrtaceae

Eugenia uniflora L. synonymous include *E. michelii* Lam., *Stenocalyx michelii* (Lam.) O. Berg, *S. lucidus* O. Berg and *Plinia rubra* Vell. Other common names include Surinam cherry, cayenne cherry, nangapiri and Brazilian cherry. Unlike most members of *Eugenia*, which are native to south east Asia, it is native of Brazil where it is commonly found between the northern part and the state of São Paulo, but the major commercial production is mainly in the state of Pernambuco. It is well adapted to tropical and subtropical regions of other South American countries, California, Florida, Caribbean Islands, China and the south of France (Kennard and Winters 1960, Silva 2006). It

is a bush or a tree that can grow up to 10 m high. The flowers are small and cream coloured and produced in profusion in the leaf axils. The fruit is a cherry that is an orange to dark red or dark purple berry in colour. It is approximately 3 cm in diameter, with eight longitudinal grooves. The pulp is juicy, sweet acid and constitutes about 77% of the weight. It is similar in colour to the skin and usually contains a single seed (Kennard and Winters 1960, Silva 2006). The tea prepared from the leaves of *E. uniflora* has been used against fever, infections and to lower blood pressure. Melo *et al.* (2007) identified the impact aroma compounds in the leaves as furanodiene and its rearrangement product, furanoelemene (or curzerene, 50.2%), β -elemene (5.9%) and α -cadinol (4.7%) were identified as the most abundant compounds.

Kennard and Winters (1960) stated that it was a good source of calcium and a fair source of iron and phosphorous. Oliveira *et al.* (2006) reported that monoterpenes were the largest class of volatiles in the fruits, comprising 75% of the 29 volatile compounds identified with the isomeric hydrocarbon ocimene being the major substance, followed by β -pinene. The main compounds contributing to fruit flavour were sesquiterpenes and ketones that are present in the essential oil, specifically β -damascenone, 5,6,7,7a-tetrahydro-4-4-7a-trimethyl-2(4H)-benzofuranone, germacrene B, spathulenol, selina-1,3,7-trien-8-one, 10-(1-methylethenyl)-(E, E)-3,7-cyclodecadien-1-one, farnesyl acetone and 2-ethyl-2-methyl-tridecanol (Malaman *et al.* 2010).

Harvesting

Harvesting is when the skin of the fruit changes to orange, red or purple that is normally some 50 days after flowering. In a comparison between harvesting at the red-orange and predominantly red stages Dos Santos *et al.* (2006) found that those harvested at the red-orange stage had a longer postharvest life.

Postharvest physiology

Akamine and Goo (1979b) found that fruits of *E. uniflora* as well as *E. cuminii*, *E. malaccensis* and *E. jambos* exhibited typical respiratory behaviour of non-climacteric fruits, including the response to exogenous ethylene treatment.

Storage

Mélo *et al.* (2000) reported that they can be stored for only 1 day in ambient conditions in Pernambuco, but they could be stored at 8 °C for up to 5 days. Dos Santos *et al.* (2006) stored red pitanga at 10 °C and 90% r.h., 14.5 °C and 90% r.h. or room temperature of 21–25 °C in PVC film bags. Strage at 10 °C proved the best and resulted in a postharvest life of 4 days more than storage without PVC bags.

Plum

Rosaceae

Prunus domestica L. It is believed to have originated in the near East and has been grown in parts of Europe for many centuries. The trees are deciduous and slender with small white scented flowers. The fruit is a drupe that is borne singly or in twos or threes (Figure 112). It will freeze at about –2.4 to –2.0 °C (Wright 1942). Crisosto and Kader (2002e) reported that the freezing point varied from –2 to –1 °C depending on TSS. The chemical content was given by USDA (2012) in Table 166.



Figure 112 Monarch plums, ready for harvesting, growing in the United Kingdom. See colour plate section.

Table 166 The composition of plum fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.23 g	Thiamine	0.028 mg
Energy	46 kcal	Riboflavin	0.026 mg
Protein	0.70 g	Niacin	0.417 mg
Total lipid (fat)	0.28 g	Vitamin B-6	0.029 mg
Carbohydrate, by difference	11.42 g	Folate	5 µg DFE
Total dietary fibre	1.4 g	Vitamin B-12	0.00 µg
Total sugars	9.92 g	Vitamin A	17 µg RAE
Calcium	6 mg	Vitamin A	345 IU
Iron	0.17 mg	Vitamin E (α-tocopherol)	0.26 mg
Magnesium	7 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	16 mg	Vitamin D	0 IU
Potassium	157 mg	Vitamin K (phyloquinone)	6.4 µg
Sodium	0 mg	Fatty acids, total saturated	0.017 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.134 g
Total ascorbic acid	9.5 mg	Fatty acids, total polyunsaturated	0.044 g

Preharvest treatment

Effects of either 100 or 200 mg L⁻¹ aminoethoxy-vinylglycine (AVG) applied 2 weeks before harvesting decreased their firmness during subsequent storage compared to those not treated. Also with the 100 mg⁻¹ AVG treatment there was a decrease in their total phenolics and total antioxidant activity. They concluded that AVG treatments generally had negative impacts on individual phenolic compounds (Ozturk *et al.* 2012).

Harvesting

Harvest maturity is assessed by colour change from green to red or yellow, feeling soft to the touch and the development of an aroma. Destructive methods can be used on samples. These include soluble solids content, which should be at least 17–18% for Prune (Phillips and Armstrong 1967), 13.4% for Beauty or more than 16% for Queen Ann (Hulme 1971). Pressure tests can be used (Hulme 1971), but it is usually easier to test texture by feel. Magnetic resonance imaging has been used to obtain images of bruises (Chen *et al.* 1989), which could be used for grading out damaged fruit in the packhouse.

1-MCP

Manganaris *et al.* (2008) reported that both the European plum (*Prunus domestica*) and the Japanese plum (*P. salicina*) responded to 1-MCP by delayed ripening.

Precooling

Air cooling in a conventional cold store was the most suitable, forced-air cooling with high humidity was also suitable and hydrocooling was less suitable and vacuum cooling was unsuitable (MAFF n.d.).

Postharvest physiology

It is classified as climacteric. Ethylene production was given as 0.01–5 µl kg⁻¹ h⁻¹ at 0 °C, 0.02–15 µl kg⁻¹ h⁻¹ at 5 °C, 0.04–60 µl kg⁻¹ h⁻¹ at 10 °C and 0.1–200 µl kg⁻¹ h⁻¹ at 20 °C. The lower values of this range were for mature but unripe fruit while the higher values were for ripe fruit (Crisosto and Kader 2002e). They gave the respiration rates as 2–3 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 8–12 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 16–24 mg CO₂ kg⁻¹ h⁻¹ at 20 °C.

Storage

At room temperature of 20 °C and 60% r.h. they could be kept for only 2 days (Mercantilia 1989). Many cultivars are subject to chilling injury, but this is often not detected until they are removed from storage for marketing when they decay, shrivel and the flesh becomes brown (Lutz and Hardenburg 1968). Anonymous (1968) also reported that the odour and colour might be abnormal after exposure to chilling temperatures. Fidler (1963) found that at –0.5 °C Victoria could be stored for 3 weeks. However, if the fruit were warmed to 18 °C for 2 days after 15 days in storage and then re-cooled the storage life could be extended to 5 or 6 weeks in total. Hardenburg *et al.* (1990) also showed that storage at –0.5 °C and 1% O₂ with intermittent warming could increase the storage life of plums. Fidler (1963) stated that Japanese cultivars are subject to chilling injury and for export from South Africa to Europe they could be transported at alternating temperatures of –5 °C and 7–10 °C although he did not give the period at each temperature. General refrigerated storage recommendations include

- -0.5 to 1°C and 85–90% r.h. for 2–8 weeks (Anonymous 1967);
- 0°C and 90–95% r.h. for 20 days (Mercantilia 1989);
- 2°C for 15 days (Mercantilia 1989);
- 8°C for 8 days (Mercantilia 1989);
- -0.5°C with 90–95% r.h. for 14–28 days (SeaLand 1991);
- -1.1 to 0°C with 90–95% r.h. (Crisosto and Kader 2002e).

Crisosto and Kader (2002e) summarized optimum temperatures for some cultivars grown in the United States as follows: Blackamber, Fortune and Angeleno at 0°C were greater than 5 weeks; Show Time, Friar, and Howard Sun developed chilling injury symptoms within 4 weeks, even when stored at 0°C . In all plum cultivars, a much longer market life was achieved when stored at 0°C than at 5°C . Other storage recommendations for specific cultivars were as follows:

Alu Bokharo

- 0 – 1.7°C and 85–90% r.h. for 2 weeks with 5.2–9.6% weight loss (Pantastico 1975).

Castleman

- -0.6 to 1°C to 1°C and 90–95% r.h. for 1 month (Lutz and Hardenburg 1968);
- -0.5 to 0°C and 90–95% r.h. for 4–5 weeks for well-matured fruit (Hardenburg *et al.* 1990).

Climax

- 0.5 – 0°C and 90–95% r.h. for 4–5 weeks for well-matured fruit (Hardenburg *et al.* 1990).

Eldorado

- -0.6 to 1°C to 1°C and 90–95% r.h. for 1 month (Lutz and Hardenburg 1968);
- -0.5 to 0°C and 90–95% r.h. for 4–5 weeks for well-matured fruit (Hardenburg *et al.* 1990).

Gaviota

- 0 – 1.7°C and 85–90% r.h. for 3 weeks with 5.2–7.8% loss (Pantastico 1975);
- 0°C and 90–95% r.h. for 10 days followed by 7°C and 90–95% for 7 days (Snowdon 1990).

Giant Prune

- 0°C and 90–95% r.h. for 10 days followed by 10°C and 90–95% for 7 days (Snowdon 1990).

Hale

- 0 – 1.7°C and 85–90% r.h. for 4 weeks with 5.2–12.9% loss (Pantastico 1975).

Japanese types

- 4.4°C for early fruit (Phillips and Armstrong 1967).

Kelsey

- 0°C and 90–95% r.h. for 10 days followed by 10°C and 90–95% for 7 days South Africa (Snowdon 1990).

Nubiana

- -0.6 to 1°C to 1°C and 90–95% r.h. for 1 month (Lutz and Hardenburg 1968).

President

- 0°C for 3–6 weeks then 6 – 8°C for 6 weeks in Australia (Fidler 1963).

Queen Ann

- -0.6 to 1°C to 1°C and 90–95% r.h. for 1 month (Lutz and Hardenburg 1968).

Rubio

- 0 – 1.7°C and 85–90% r.h. for 3 weeks with 5.2–7.8% loss (Pantastico 1975).

Santa Rosa (Late)

- -0.6 to 1°C to 1°C and 90–95% r.h. for 1 month (Lutz and Hardenburg 1968);
- -0.5 to 0°C and 90–95% r.h. for 4–5 weeks for well-matured fruit (Hardenburg *et al.* 1990);
- 0°C and 90–95% r.h. for 3–4 weeks from California (Snowdon 1990);
- 0°C and 90–95% r.h. for 10 days followed by 7°C and 90–95% for 7 days from South Africa (Snowdon 1990).

Satsuma

- 0°C for 3–6 weeks then 6 – 8°C for 6 weeks in Australia (Fidler 1963).

Shiro

- 0 – 1.7°C and 85–90% r.h. for 4 weeks with 5.2–12.9% loss (Pantastico 1975).

Victoria

- 0 – 1°C and 90–95% r.h. for 3 weeks from the United Kingdom (Snowdon 1990).

Wickson

- 0 °C for 3–6 weeks then 6–8 °C for 6 weeks in Australia (Fidler 1963);
- –0.5 to 0 °C and 90–95% r.h. for 4–5 weeks for well matured (Hardenburg *et al.* 1990).

Controlled atmosphere storage

In storage at –0.5 °C chilling injury to Monarch was some 25% less in 2.5% CO₂ with 5% O₂ than in air (Anonymous 1968). CA storage recommendations include

- 0–5 °C with 0–5% CO₂ and 1–2% O₂ was reported to have a good effect on storage, but not being used commercially (Kader 1985);
- At 1 °C with 12% CO₂ and 2% O₂ the cultivar Buhler Fruhwetsche had a good appearance, taste and firmness after 4 weeks of storage, with no CO₂ injury detected during storage at concentrations below 16% (Steif 1989);
- –0.5 °C with 0–5% CO₂ and 2% O₂ (SeaLand 1991);
- 1–2% O₂ + 3–5% CO₂ to reduce decay incidence (Crisosto and Kader 2002e).

Ripening

For slow ripening cultivars, such as Black Beaut, Casselman, Late Santa Rosa, Kelsey, Nubiana, Queen Ann and Roysum, exposure to 100 µl L^{–1} ethylene at 20 °C for at least 24 h was needed for faster and more uniform ripening (Crisosto and Kader 2002e).

Diseases

The infection with Brown rot caused by *Monilia fructicola* begins during flowering and rotting may occur before harvest, but often postharvest. Orchard sanitation to minimize infection sources, preharvest fungicide application and prompt precooling after harvest can help to control the disease. Grey mould caused by *Botrytis cinerea* can cause rotting in wet weather and also postharvest if fruit have been contaminated especially through damage. Rhizopus rot caused by *Rhizopus stolonifer* can occur postharvest especially at room temperature. Prompt precooling and storage below 5 °C was an effective control (Snowdon 1990, Crisosto and Kader 2002e). Fruit were wounded, covered with carnauba wax and then inoculated or fruit

were wounded, inoculated and then covered with carnauba wax. There was no mycelial growth of *M. fructicola* at any of the wax concentrations (1, 2, 3 and 4.5%). *R. stolonifer* was completely inhibited by carnauba wax at all concentrations except at 1%. Protective application of 4.5 and 9% carnauba wax significantly reduced disease incidences but they concluded that control of both diseases by the application of carnauba wax was inefficient (Gonçalves *et al.* 2010).

Pomegranate**Punicaceae**

Punica granatum L. It is a native of Iran and was grown in ancient Egypt and spread eastwards to the Indian subcontinent and China and most areas of the tropics, subtropics and warm temperate areas (Purseglove 1975). It is a bush 2–4 m high and is deciduous in cooler parts. The flowers are orange to red and up to 6 cm in diameter. The fruit is up to 12 cm in diameter and is a berry with a tough leathery skin, which is a brownish yellow colour with a red blush or it can be fully red. It has a persistent calyx. Inside are numerous seeds each embedded in the sweet, pink juicy pulp called the aril, which is the edible portion and is easily dislodged. It is classified as a non-climacteric fruit with no detectable levels of ethylene produced during storage (Nanda *et al.* 2001). They were traditionally dislodged and eaten with a pin in Britain. The chemical content was given by USDA (2012) in Table 167.

Harvesting

This should be when they are mature, which is difficult to judge, but can be related to skin colour changes. If too mature they have a tendency to split. In Iran the optimum harvesting time was when the soluble solids content reached 17.5% (Sherafatian 1994). Wardlaw (1937) recommended clipping the fruit stalks not pulling them.

Prestorage treatments

Sayyari *et al.* (2009) found that dipping fruit in salicylic acid, especially at 2 mM concentration, was highly effective in reducing chilling injury and electrolyte leakage in the peel of pomegranate, as well

Table 167 The composition of pomegranate fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	77.93 g	Thiamine	0.067 mg
Energy	83 kcal	Riboflavin	0.053 mg
Protein	1.67 g	Niacin	0.293 mg
Total lipid (fat)	1.17 g	Vitamin B-6	0.075 mg
Carbohydrate, by difference	18.70 g	Folate	38 µg DFE
Total dietary fibre	4.0 g	Vitamin B-12	0.00 µg
Total sugars	13.67 g	Vitamin A	0 µg RAE
Calcium	10 mg	Vitamin A	0 IU
Iron	0.30 mg	Vitamin E	0.60 mg
		(α-tocopherol)	
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	36 mg	Vitamin D	0 IU
Potassium	236 mg	Vitamin K	16.4 µg
		(phylloquinone)	
Sodium	3 mg	Fatty acids, total saturated	0.120 g
Zinc	0.35 mg	Fatty acids, total monounsaturated	0.093 g
Total ascorbic acid	10.2 mg	Fatty acids, total polyunsaturated	0.079 g

as ascorbic acid loss compared with that observed in control fruit during storage at 2 °C for 3 months. Sayyari *et al.* (2012) subsequently reported that dipping fruit in 0.1, 0.5 or 1.0 mM acetyl salicylic acid immediately after harvest reduced chilling injury and helped maintain their quality during storage at 2 °C. Fruits that had been treated with acetyl salicylic acid had improved retention of sugars, organic acids, total phenolics and anthocyanins.

Chilling injury

There was no decay during storage at 0 °C but an increased the risk of chilling injuries such as pitting and husk scald, while storage at 5 °C reduced these injuries but fungal attacks were not inhibited. Intermittent warming alleviated chilling injury (pitting and husk scald) without any incidence of decay (Artes *et al.* 1998). In later work on the cultivar Mollar de Elche, Artes *et al.* (2000) found that 2 °C was the optimum storage temperature. Sayyari *et al.* (2012) reported that chilling injury occurred during storage at 2 °C and the symptoms were pitting and browning and increased softening, ion leakage and respiration rate. D'Aquino *et al.* (2010) reported that exposure to temperatures below 5–6 °C chilling injury appeared

as pitting of the skin, browning of the white segments separating the arils and discoloration of the arils and husk scald, which generally was more severe at temperatures of 6–10 °C.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 1–2 weeks. Intermittent warming of 1 day at 20 °C every 6 days during storage of the cultivar Mollar at 0 °C and 95% r.h. for 80 days was the best treatment for maintaining the red skin colour. However the red colour of the pulp was maintained better with intermittent warming at 5 °C and 95% r.h. for 80 days than at 0 °C (Artes *et al.* 1998). After shelf life for 3 days at 15 °C and 75% r.h., intermittent warming for 1 day every 6 days during storage at 2 °C and 95% r.h. for 90 days was the only treatment that resulted in fruits with a flavour similar to that at harvest (Artes *et al.* 2000). Refrigerated storage recommendations include

- 1.1–1.7 °C and 80% r.h. (Wardlaw 1937);
- 0 °C or 4.4 °C for 7 months in India (Lutz and Hardenburg 1968);
- 0–1.7 °C and 85–90% r.h. for 11 weeks for the cultivar Khandari (Pantastico 1975);
- 0 °C and 90% r.h. for 2 months (Mercantilia 1989);
- 1, 5 and 10 °C and 90–95% r.h. for 2 months for the cultivar Gok Bahce for 2 months with 4.9, 5.7 and 4.6% weight loss, respectively (Koksall 1989);
- 5–6 °C and 90% r.h. for 3–4 months (Snowdon 1990);
- 0 °C and 90% r.h. for 2–4 months (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 1 month or 5 °C and 90–95% r.h. for 2 months (Hardenburg *et al.* 1990);
- 3 °C (Sherafatian 1994);
- 5 °C and 90–95% r.h. for 28–56 days (SeaLand 1991);
- 1 °C for the cultivars Malas Torsh, Saveh Hendes, Shirin Paeizeh and Sefid Torsh for 4½ months (Askary and Shahedi 1994);
- 6 °C and 85–90% r.h. for 5 months for the cultivar Hicaz (Kupper *et al.* 1994);
- 8 or 10 °C and 85–90% r.h. for 50 days for the cultivar Hicaz (Kupper *et al.* 1994);
- 2 °C and 95% r.h. (Artes *et al.* 2000).

Controlled atmosphere storage

Controlled atmosphere storage had a slight to no effect (SeaLand 1991). Kupper *et al.* (1994) recommended 6 °C and 85–90% r.h. with 6% CO₂ and 3% O₂ for 6 months for Hicaz.

Modified atmosphere packaging and coating

Individual shrink-film-wrapped fruits with either BDF-2001 polyolefin film or D-955 polyolefin film could be stored for 12, 9 and 4 weeks at 8, 15 and 25 °C, respectively, compared to 8, 6 and 2 weeks with Semperfresh coating and 7, 5 and 1 week for non-wrapped fruits under similar storage conditions (Nanda *et al.* 2001). Changes in acidity, sugars and ascorbic acid of the shrink-wrapped fruits were lower than those of non-wrapped fruits during 12 weeks of storage at 8 °C. Fruit that were shrink wrapped also had a lower respiration rate than non-wrapped fruit. D'Aquino *et al.* (2010) found that polyolephinic heat-shrinkable film wrapping almost completely inhibited weight loss and husk scald and preserved fruit freshness for the storage time of 12 weeks at 8 °C and 90% r.h. Also there was no significant difference in decay incidence between film wrapped and those not wrapped but after subsequent shelf life at 20 °C and 65–70% r.h. for 1 week wrapped fruit had significantly higher decay levels.

Diseases

The main losses in storage at 5 °C were due to decay caused by *Penicillium* spp. (Artes *et al.* 2000). D'Aquino *et al.* (2010) found that dipping fruit in 600 mg L⁻¹ fludioxonil resulted in 50–67% less decay than those not treated after 12 weeks at 8 °C plus 1 week shelf life at 20 °C in either shrink film or not wrapped.

Disorders

Internal breakdown can occur and results in the pulp having a light streaky appearance and a flat taste (Pantastico 1975). The cause of this disorder is not known. Lu and McCarthy (2012b) reported that black heart developed inside the fruit without affecting the rind so that it is not possible to detect it until the consumer opens it. They developed a system using

proton nuclear magnetic resonance relaxometry that was shown to have 92% accuracy in detecting the presence of black heart in pomegranate fruit without affecting their quality or marketability. In some countries like Pakistan the fruit are opened and the coated seeds are sold on the market to overcome this problem. This also means that the fruit is in a convenient ready-to-eat form and adds value for the producer.

Pond apple

Annona glabra L. Other common names include alligator apple and monkey apple.

They grow wild in the north and north-east of Brazil and are cultivated in Brazil and Central America (Bicas *et al.* 2011). It is a small tree. The fruit is similar to that of *A. reticulata* but it has an yellow or orange coloured pulp, which Kennard and Winters (1960), surprisingly, reported was inedible although Santos *et al.* (1998) described the pulp as edible. They also found that the most abundant class of compounds in the aroma was terpenoids, principally α -pinene, limonene, α -phellandrene and (*E*)- β -ocimene. The concentrations of terpenoid compounds vary according to the different stages of ripening.

Prickly pear

Cactaceae

Opuntia spp. *O. ficus-indica* (L.) Mill., *O. robusta* and *O. amyclaea*. Other common names include barberry fig, belles, cactus fruit, Indian fig, nopalitos and tuna. The fruit have a thick peel that is purple, red, orange, yellow or green in colour when mature and are covered with sharp spines. It is ovoid and 5–7 cm long (Figure 113). The pulp is sub-acid, juicy and contains numerous seeds. The chemical content was given by USDA (2012) in Table 168.

Harvesting

Harvest maturity is usually judged on peel colour. In a study of the cultivar Gialla in Italy by Inglese *et al.* (1999), the number of days required to reach commercial harvest maturity changed with the time of bud burst, but the thermal time (40 × 103 growing



Figure 113 Prickly pear fruit imported into Britain being offered for sale in a wholesale market. See colour plate section.

Table 168 The composition of prickly pear fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	87.55 g	Zinc	0.12 mg
Energy	41 kcal	Total ascorbic acid	14.0 mg
Protein	0.73 g	Thiamine	0.014 mg
Total lipid (fat)	0.51 g	Riboflavin	0.060 mg
Carbohydrate,	9.57 g	Niacin	0.460 mg
by difference			
Total dietary	3.6 g	Vitamin B-6	0.060 mg
fibre			
Calcium	56 mg	Folate	6 µg DFE
Iron	0.30 mg	Vitamin B-12	0.00 µg
Magnesium	85 mg	Vitamin A	2 µg RAE
Phosphorus	24 mg	Vitamin A ^a	43 IU
Potassium	220 mg	Fatty acids, total	0.067 g
		saturated	
Sodium	5 mg	Fatty acids, total	0.075 g
		monounsaturated	
		Fatty acids, total	0.213 g
		polyunsaturated	

^a<http://ndb.nal.usda.gov/ndb/foods/show/2461?fg=Fruits+and+Fruit+Juices&man=&facet=&format=&count=&max=25&offset=225&sort=&qlookup=#id-aid-a>

degree hours) did not. Glochids (small spines) of cactus pear negatively affect harvest operations, quality and their acceptance so Corrales-Garcia and Gonzalez-Martinez (2001) investigated ways of removing them from *O. amyclaea*. To do this gibberellic acid at 100 µl L⁻¹ was sprayed over flower buds in six consecutive applications every 7 days during their development also, solutions of Ethephon (Ethrel) at 700 µl L⁻¹ a.i. were sprayed over the buds immediately after fruit set, alone or

in combination with gibberellic acid applications. After the mechanical effect of harvest, gibberellic acid + Ethephon caused up to 90% abscission of glochids compared with the controls (37%), while Ethephon alone caused 79% of glochids to abscise in the best case. None of the treatments negatively affected the quality of the fruit in terms of soluble solids concentration, acidity, colour, weight of pulp and weight of peel (Corrales-Garcia and Gonzalez-Martinez 2001). Fruit harvested with a bit of stem may be cured at 15–20 °C with airflow so the bit of stem dries and falls off before the fruit are packed. This prevents damage to the stem end and greatly reduces decay incidence (Cantwell 2002).

Prestorage treatments

Prestorage dipping of the fruit in water at 55 °C for 5 min or conditioning at 38 °C in saturated air for 24 h improved their quality during marketing and could reduce the need for postharvest fungicides (Cantwell 2002). Hot water dipping at 52 °C for 3 min and hot air treatment at 37 °C for 24–72 h sealed the microwounds and cracks normally present in untreated fruits and caused the disappearance of platelets, resulting in a relatively homogeneous skin surface, presumably due to melting of wax layers. Occlusion of possible entry points for wound pathogens by melting the surface may contribute to protecting the fruit against decay (D'hallewin *et al.* 1999). Schirra *et al.* (1999a) found that the heat treatment at 37 °C in saturated humidity for 30 h reduced decay during subsequent storage at 6 °C for 45 days and simulate a marketing period of 4 days at 20 °C, retained visual quality, prevented chilling injury but resulted in a higher ethylene production rate compared with non-treated fruit.

Postharvest physiology

They are non-climacteric fruit that produces very low amounts of ethylene at about 0.2 µl kg⁻¹ h⁻¹ at 20 °C and are not sensitive to ethylene exposure. Their respiration rate was 27–36 mg (15–20 µl) CO₂ kg⁻¹ h⁻¹ at 20 °C (Cantwell 2002). Schirra *et al.* (1997) gave their respiration rate as 16–19 mg CO₂ kg⁻¹ h⁻¹ at 5 °C, 38–42 mg CO₂ kg⁻¹ h⁻¹ at 10 °C, 52–59 mg CO₂ kg⁻¹ h⁻¹ at 15 °C and 68–79 mg CO₂ kg⁻¹ h⁻¹ at 20 °C.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 5–7 days. Chilling injury may occur in some varieties during storage at less than 5 °C and in some cases less than 10 °C. In storage at 6 °C chilling occurred in a red fruit variety after only 2 weeks but fruit from other varieties were stored for several weeks without showing symptoms of chilling injury. Symptoms include pitting, surface bronzing and dark spots on the peel and increased susceptibility to decay (Schirra *et al.* 1999b). Application of calcium chloride, conditioning and intermittent warming has had variable success in reducing chilling injury (Cantwell 2002). Refrigerated storage recommendations include

- –0.5 to 0.5 °C and 85–90% r.h. for 2 months (Berger *et al.* 1978, quoted by Yahia 2011b);
- 6–9 °C (Chessa and Barbera 1984, quoted by Yahia 2011b);
- 5 °C and 90–95% r.h. for 3–4 weeks (Mercantilia 1989);
- 8–10 °C and 90% r.h. for 2 weeks (Snowdon 1990);
- 5 °C and 90–95% r.h. for 3–4 weeks for prickly pears (SeaLand 1991);
- 2.2 °C and 90–95% r.h. for 3 weeks for cactus pears (SeaLand 1991).

Diseases

Common postharvest pathogens on cactus fruit are mostly fungi and include *Fusarium* spp., *Alternaria* spp. and *Penicillium* spp., but yeasts and bacteria also cause decay. Hot water dips at 53–55 °C for 5 min and waxes that contain fungicide may reduce surface decay but are not effective when there is damage to the stem ends (Cantwell 2002, Yahia 2011b). Preharvest calcium sprays resulted in less postharvest decay (Schirra *et al.* 1999b).

Pomelo

Rutaceae

Citrus grandis (L.) Osbeck, *Citrus maxima* Merr., *C. decumana* L. Other common names include pummelos and shaddock. It is native to southeastern Asia and may have been introduced into China around 100 BCE and was distributed to southern

Table 169 The composition of pomelo fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	89.10 g	Potassium	216 mg
Energy	38 kcal	Sodium	1 mg
Protein	0.76 g	Zinc	0.08 mg
Total lipid (fat)	0.04 g	Total ascorbic acid	61.0 mg
Carbohydrate, by difference	9.62 g	Thiamine	0.034 mg
Total dietary fibre	1.0 g	Riboflavin	0.027 mg
Calcium	4 mg	Niacin	0.220 mg
Iron	0.11 mg	Vitamin B-6	0.036 mg
Magnesium	6 mg	Vitamin B-12	0.00 µg
Phosphorus	17 mg	Vitamin A	0 µg RAE
		Vitamin A	8 IU

Thailand, Japan, southern India, Malaya, Indonesia, New Guinea and Tahiti. It probably originated in the region of Malaysia, the Indian archipelago and southern China. There is a legend that it was apparently first taken to the West Indies in a ship whose captain's name was Shaddock (if such a person ever existed) when it stopped over at Barbados on its way to England. It is tropical or subtropical and flourishes naturally at low altitudes close to the sea (Morton 1987).

It is a tree that may grow to 15 m high, with a somewhat crooked trunk with low, irregular branches, but there are also dwarf varieties. The flowers are fragrant, borne singly or in clusters in the leaf axils or sometimes in terminal racemes. The fruit is a berry or hesperidium, which is non-climacteric. Superficially the fruit looks like a grapefruit (*C. pardisi*) and ranges in shape from ovoid to pyriform with a pronounced flattening of the stylar end in most cultivars. Its peel is very thick and easy to peel, and the flesh has very pronounced juice sacks with a rubbery texture and appearance (Figure 114). It has a sweet mild flavour, not bitter like grapefruit. Generally, there are only a few seeds, and a pummelo pollinated by another pummelo is apt to have numerous seeds but if pollinated by sweet orange or mandarin orange, the progeny will not be seedy (Morton 1987). The chemical content was given by USDA (2012) in Table 169.

Harvesting

Harvest maturity is judged on the skin texture. In Thailand, fruits are generally harvested when just



Figure 114 Pomelos in China showing the thick skin. In Thailand some varieties have much thinner skins and therefore a larger edible portion. (Photo: Dr Wei Yuqing. Reproduced with permission.)



Figure 115 Pomelo being harvested in China. (Photo: Dr Wei Yuqing. Reproduced with permission.)

beginning to turn yellow (Morton 1987). As the fruit develops it has a fairly rough skin that becomes progressively smoother as it matures. Harvesting is by hand by clipping the fruit stalk (Figure 115).

Curing

Curing at 34–35 °C for 48–72 h, not later than 48 h after harvest reduced decay and various blemishes without deleterious effects (Ben Yehoshua *et al.*

1989a). Sealing the fruit in plastic film before curing was said to be essential to reduce weight loss (Ben Yehoshua *et al.* 1989a).

Storage

Morton (1987) reported that paper-wrapped fruits in ventilated crates have kept in good condition for 6–8 months during sea transport to Europe. The fruits kept for long periods because of the thick peel but after 3 months the peel may be deeply wrinkled but the pulp will be juicier and of more appealing flavour than in the fresh fruit. However, if stored too long, they may become bitter. She also quoted that ‘According to an old Chinese Atlas, the fruits of the “Double” pummelo, if hung in the house, will remain in good condition for a year’. Refrigerated storage recommendations include

- 7.2–8.9 °C and 85–90% r.h. for 12 weeks (Pantastico 1975);
- 11 °C and 90% r.h. for 8–12 weeks (Waks *et al.* 1988);
- 10–15 °C and 90% r.h. (Snowdon 1990);
- 7.2 °C and 85–90% r.h. for 84 days (SeaLand 1991).

Packaging fruit sealed individually in plastic films reduced decay during long-term storage at 11 °C (Waks *et al.* 1988).

Quince

Rosaceae

Cydonia oblonga Mill. It is probably a native of western Asia and the warmer regions of southeastern Europe and Asia Minor where it grows wild and where it has been cultivated from ancient times. It is sometimes said that the golden apple given by Paris to Aphrodite was in fact a quince. The fruit is a pome and is classified as climacteric. They are borne on trees that can be up to 6 m high. They can be either apple or pear shaped and are similar to those fruit in structure, but they have up to 20 carpels compared to only two in apples and pears. The flesh is greenish white and very acidic and are rarely eaten fresh but are commonly made into jam when the flesh turns a dull pink colour. The chemical content was given by USDA (2012) in Table 170.

Table 170 The composition of quince fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	83.80 g	Zinc	0.04 mg
Energy	57 kcal	Total ascorbic acid	15.0 mg
Protein	0.40 g	Thiamine	0.020 mg
Total lipid (fat)	0.10 g	Riboflavin	0.030 mg
Carbohydrate,	15.30 g	Niacin	0.200 mg
by difference			
Total dietary fibre	1.9 g	Vitamin B-6	0.040 mg
Calcium	11 mg	Folate	3 µg DFE
Iron	0.70 mg	Vitamin B-12	0.00 µg
Magnesium	8 mg	Vitamin A	2 µg RAE
Phosphorus	17 mg	Vitamin A	40 IU
Potassium	197 mg	Fatty acids, total saturated	0.010 g
Sodium	4 mg	Fatty acids, total monounsaturated	0.036 g
		Fatty acids, total polyunsaturated	0.050 g

As the fruit develops the skin is downy and becomes smooth as it ripens and turns a golden yellow colour. They store well in ambient temperatures, but a refrigerated storage recommendation is -0.5°C and 90–95% r.h. for 60–90 days (SeaLand 1991).

Rambutan

Sapindaceae

Nephelium lappaceum L. It is a native of Malaysia. Fruit are borne in clusters on handsomely spreading trees and are an ovoid-shaped berry that can be up to 6 cm long. It is red to orange yellow in colour when mature and covered in soft spines (Figure 116), which are referred to as *spinterns*. They contain one large seed surrounded by white melting subacid flesh (Purseglove 1968). In some varieties the pulp is attached to the seeds, in others it is free.

Harvesting

The colour of the spines and the skin are used as guides to harvest maturity. The colour varies between different cultivars and fruit are considered over mature when the tips of the spines turn brown (Lam and Kosiyachinda 1987). Harvest maturity may also be judged on the time after full flowering. In

**Figure 116** Rambutan on sale in a local market in Sri Lanka.

Thailand this is 90–120 days, in Indonesia 90–100 days and in Malaysia 100–130 days (Kosiyachinda 1968).

Packaging

Packing fruit in sawdust reduced fruit weight loss and kept them in good condition, but wax coating of fruits was less effective (Mendoza *et al.* 1972).

Postharvest physiology

They are non-climacteric fruit and have an ethylene production rate of less than $0.04 \mu\text{l kg}^{-1} \text{h}^{-1}$. Storage in $5 \mu\text{l L}^{-1}$ and ethylene and 9–12% CO_2 at 7.5 or 10°C did not significantly affect their rate of colour loss (O'Hare *et al.* 1994). Respiration rate was about $23\text{--}57 \mu\text{l CO}_2 \text{kg}^{-1} \text{h}^{-1}$ at 25°C for mature fruit; immature fruit respiration rates are higher (Mendoza *et al.* 1972).

Storage

At 20°C and 60% r.h. they had a storage life of only 3–5 days (Mercantilia 1989). Chilling injury was reported to occur at 7°C as browning of both the skin and spines (Mendoza *et al.* 1972, Somboon 1984). Refrigerated storage recommendations include

- 10°C and 90–95% r.h. for 1–2½ weeks with 6–12% weight loss (Pantastico 1975);
- 10°C and 90% r.h. for 1–2 weeks (Mercantilia 1989);

- 10–12 °C and 95% r.h. for 1–2 weeks (Snowdon 1990);
- 7.5 °C for 15 days for the cultivars R162, Jit Lee and R156 (O'Hare *et al.* 1994);
- 10 °C for 11–13 days for the cultivars R162, Jit Lee and R156 (O'Hare *et al.* 1994);
- 13 °C and 95–100% r.h. for 12 days (Kanlayanarat *et al.* 2000).

Controlled atmosphere storage

Kader (1993) in a review recommended 10 °C, with a range of 8–15 °C, combined with 7–12% CO₂ and 3–5% O₂. Kader (1993) also claimed that they could tolerate CO₂ levels of greater than 20% and that exposure of less than 1% O₂ resulted in an increase in decay. Storage of cultivar R162 at 7.5 °C in 9–12% CO₂ retarded colour loss and extended shelf life by 4–5 days but storage in 3% O₂ did not significantly affect the rate of colour loss (O'Hare *et al.* 1994).

Modified atmosphere packaging

Fruit have been stored successfully in PE film bags (Mendoza 1979) with storage times of about 10 days in perforated bags and 12 days in non-perforated bags at 10 °C. Storage in sealed PE film bags or plastic containers was effective in reducing water loss (Mendoza *et al.* 1972). They also recommended storage in sealed PE film bags at 10 °C for 12 days but at high storage temperatures (32–37 °C) perforation of the bags was preferable. Dipping the fruit 100 µL L⁻¹ benomyl before packing in the trays could control storage decay. Kanlayanarat *et al.* (2000) showed that the cultivar Rong-Rien stored in 0.01- or 0.04-mm-thick polyethylene bags at 13 °C and 95–100% r.h. had the longest storage life of 18 days, compared with 16 days in fruits stored in 0.08 mm thick and 12 days in controls. All fruit in polyethylene bags had reduced moisture loss and delayed spine discoloration. The following atmospheres developed in the sealed bags:

- 0.01 mm polyethylene bags 15–16% O₂ and 2–3% CO₂;
- 0.04 mm polyethylene bags 3–5% O₂ and 10–11% CO₂;
- 0.08 mm polyethylene bags 1–2% O₂ and 15–16% CO₂.

Disease

Sangchote *et al.* (1992) considered *Collectotrichum gloeosporioides* and *Botryodiplodia theobromae* the most serious pathogens but others included *Pestalotiopsis* spp. and *Phomopsis* spp. They found that the fungi associated with decay varied with storage temperature. *Trichoderma harzianum* isolated in soil samples from rambutan orchards had an antagonistic effect against stem rot *B. theobromae*, anthracnose *C. gloeosporioides* and brown spot *Gliocephalotrichum microchlamydosporium*. Treatment with *T. harzianum* had no detrimental effects on the overall quality and colour of the fruits (Sivakumar *et al.* 2000). They also found that the application of *T. harzianum* and potassium metabisulphite effectively controlled the incidence and severity of the three postharvest diseases and maintained the overall quality and colour of the fruit in storage at 13.5 °C and 95% r.h. for 18 days.

Raspberry

Rosaceae

Rubus idaeus L. It can be classified into the European red raspberry *R. idaeus* subspecies *vulgatus* Arrhen and the American red raspberry *R. idaeus* subspecies *strigosus* Michx. There are also *R. occidentalis* L. the black raspberry and *R. leucodermis* Douglas ex Torr. & A. Grey the whitebark raspberry. *R. glaucus* L. is a South American tetraploid black raspberry and *R. neglectus* Peck. is the purple raspberry that resulted from crosses between black and red raspberries (Perkins-Veazie 2002c).

The fruit is a collection of drupes with a hollow centre where the fruit detaches from the receptacle. It is classified as a non-climacteric fruit. They will freeze at about –1.4 to –1.1 °C (Wright 1942). Esters and terpenes were the most abundant aromatic fractions in raspberries, which exhibited a significant decline ($p < 0.05$) in the total amount of volatiles after treatment with methyl jasmonate in combination with ethanol (Blanch *et al.* 2012). The chemical content was given by USDA (2012) in Table 171.

Harvesting

They are ready for harvest when they become a bright even red and are easily detached from the

Table 171 The composition of raspberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	85.75 g	Thiamine	0.032 mg
Energy	52 kcal	Riboflavin	0.038 mg
Protein	1.20 g	Niacin	0.598 mg
Total lipid (fat)	0.65 g	Vitamin B-6	0.055 mg
Carbohydrate, by difference	11.94 g	Folate	21 µg DFE
Total dietary fibre	6.5 g	Vitamin B-12	0.00 µg
Total sugars	4.42 g	Vitamin A	2 µg RAE
Calcium	25 mg	Vitamin A	33 IU
Iron	0.69 mg	Vitamin E (α-tocopherol)	0.87 mg
Magnesium	22 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	29 mg	Vitamin D	0 IU
Potassium	151 mg	Vitamin K (phyllloquinone)	7.8 µg
Sodium	1 mg	Fatty acids, total saturated	0.019 g
Zinc	0.42 mg	Fatty acids, total monounsaturated	0.064 g
Total ascorbic acid	26.2 mg	Fatty acids, total polyunsaturated	0.375 g

receptacle. If harvesting is delayed the individual drupes may become detached from each other during harvesting and marketing. Mechanical harvester has been developed for raspberries but they still need hand grading to remove unsuitable fruit (Figure 16) and are really only suitable for fruit destined for processing.

Precooling

Hydrocooling and vacuum cooling were generally unsuitable, with placing in a conventional cold storage acceptable, but forced-air cooling with high humidity air was found to be the best method (MAFF n.d.).

Coating

Han *et al.* (2004) coated raspberries with chitosan, chitosan containing 5% Gluconal® CAL or chitosan containing 0.2% dl-α-tocopheryl acetate and stored them at 2 °C and 88% r.h. for 3 weeks. The coatings significantly decreased decay incidence and weight loss and delayed the change in colour and TA.

Postharvest physiology

Ethylene production varies between cultivars, from 1 to 12 µL kg⁻¹ h⁻¹ at 20 °C (Burdon and Sexton 1993, Perkins-Veazie and Nonnecke 1992). Stimulation of *Botrytis cinerea* growth can occur on raspberries in the presence of ethylene that also can result in darkening to a purple-red colour in red raspberries. Respiration rate was given in Table 172.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for just 1 day. Refrigerated storage recommendations include

- -0.6 to 0 °C and 85–90% r.h. for 5–7 days (Phillips and Armstrong 1967);
- 0 °C and 85–90% r.h. for 3–5 days (Anonymous 1967);
- 0 °C for 6 days then 18.3 °C for 1 day for marketing or up to 11 days at 0 °C (Wilkinson 1972);
- 0 °C and 85–90% r.h. for 2–3 days (Shoemaker 1978);
- 0 °C and 90–95% r.h. for 5 days (Mercantilia 1989);
- 8 °C for 3–4 days (Mercantilia 1989);
- 14 °C for 2 days (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 1–7 days (Snowdon 1990);
- -0.5 to 0 °C and 90–95% r.h. for 2–3 days (Hardenburg *et al.* 1990);
- -0.5 °C and 90–95% r.h. for 2–3 days (SeaLand 1991).

Four cultivars were harvested at the semi-ripe, ripe and slightly over-ripe stages and were stored at room temperature (20 °C) for 1 day or at 2–4 °C for 3 days followed by 1 day at room temperature. All parameters they measured, including the ratios among cyanidin-3-sophoroside,

Table 172 Respiration rate of raspberry fruit at different temperatures (source: adapted from Perkins-Veazie 2002c)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
2	16–18
4–5	18–27
10	31–39
15–16	28–55
20–21	74–175

cyanidin-3-glucoside, cyanidin-3-glucosylrutinoside and cyanidin-3-rutinoside, varied between cultivars. After storage, berry colour was darker and total anthocyanins and antioxidant capacity was higher in comparison to freshly harvested fruit. TSS and total phenols were similar between three cultivars for the three harvested maturities, but in Tulameen they increased with increasing maturity.

Controlled atmosphere storage

Controlled atmosphere storage with 20–25% CO₂ retarded the development of rots (Hardenburg *et al.* 1990). Kader (1989) recommended 0–5 °C with 15–20% CO₂ and 5–10% O₂.

Transport

Fruit used to be transported in punnets from Scotland to the south on England by non-refrigerated trucks, but wastage was very high. Precooling and transporting in refrigerated vans reduced wastage on the journey (Hulme 1971).

Redcurrant, whitecurrant

Saxifragaceae, Grossulariaceae

Redcurrant *Ribes rubrum* L., *R. sativum* Syme, whitecurrant *R. glandulosum* Grauer ex Weber, but some authorities refer to whitecurrant as a variety of *R. rubrum*. They are native to parts of Belgium, France, Norway, Sweden, Germany, the Netherlands, northern Italy, northern Spain, Portugal and Poland. Large fruited cultivars of the redcurrant were first produced in Belgium and northern France in the 17th century. They are closely related to the blackcurrant *R. nigrum*. The word currant has been used for this fruit only since 1550, taken from the fruits' resemblance to the dried currants.

They are deciduous shrubs normally growing to 1–1.5 m high, occasionally 2 m, with five-lobed leaves arranged spirally on the stems. The flowers are inconspicuous yellow-green borne in pendulous 4–8 cm racemes. They are borne towards the bases of 1-year-old stems and on spurs on older stems. Most currants have self-fertile flowers, but a few cultivars are partially self-sterile, so set more fruits with cross-pollination. The fruits contain many small



Figure 117 White currants ready for harvesting growing in Britain. See colour plate section.

seeds but they are larger and fewer in number than in blackcurrant. *R. sativum* and have some 970 seeds per 100 g of fruit weighing some 4.25 mg while *R. nigrum* has some 4450 seeds per 100 g weighing some 1.03 g (Hulme 1971). The fruit are small and when ripe they turn shiny and either red or, in the case of whitecurrants, a beautiful translucent silvery golden colour (Figure 117). There is also a pink variety. The fruits are borne in clusters called strigs and they mature in order along the strigs with the first one nearest the pedicel and the last being the terminal fruit. When mature, redcurrants have a total sugar content of some 4.4% and a total solid content of 16% made up of 10.5% soluble solids and 5.5% insoluble solids while whitecurrants have a total sugar content of 5.6% and a total solid content of 15.7% (Hulme 1971). The chemical content was given by USDA (2012) in Table 173.

Harvesting

It is normal to harvest the whole cluster of fruit together by hand when almost all of them have fully changed colour, even though the cluster will contain some under mature fruit (Hulme 1971). Therefore for eating fresh the berries can be left for about 3 weeks after they are fully coloured. Generally TSS should be about 9.5–14% and TA of about 2% (University of Wisconsin Extension Service). To avoid damaging the fruits, a whole strig should be harvested by its stem, taking care not to damage the spur. The currants can be stripped from the clusters by pulling them through the tines of a fork; the fully mature ones are

Table 173 The composition of redcurrant fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	83.95 g	Thiamine	0.040 mg
Energy	56 kcal	Riboflavin	0.050 mg
Protein	1.40 g	Niacin	0.100 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.070 mg
Carbohydrate, by difference	13.80 g	Folate	8 µg DFE
Total dietary fibre	4.3 g	Vitamin B-12	0.00 µg
Total sugars	7.37 g	Vitamin A	2 µg RAE
Calcium	33 mg	Vitamin A	42 IU
Iron	1.00 mg	Vitamin E (α-tocopherol)	0.10 mg
Magnesium	13 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	44 mg	Vitamin D	0 IU
Potassium	275 mg	Vitamin K (phylloquinone)	11.0 µg
Sodium	1 mg	Fatty acids, total saturated	0.017 g
Zinc	0.23 mg	Fatty acids, total monounsaturated	0.028 g
Total ascorbic acid	41.0 mg	Fatty acids, total polyunsaturated	0.088 g

easily removed. TSS is usually about 9.5–14% and acidity is around 2%.

Storage

If the fruits are to be stored they should be picked dry. 0–1.1 °C with 95% r.h. for up to 2½ weeks was recommended (University of Wisconsin Extension Service). Batzer and Helm (1999) recommended 0–1 °C for 2½ weeks and 1 °C and 18–20% CO₂ + 2% O₂ for 8–14 weeks for redcurrants depending on cultivar.

Red huckleberry

Ericaceae

Vaccinium parvifolium Smith. Other common names include Red Bilberry and Red Whortleberry.

It is native to the western North America, where it is common in forests from Southeastern Alaska to Central California. It occurs mostly at low to middle elevations in soil enriched by decaying wood and on rotten logs, from sea level up to about 1800 m. It is a deciduous shrub from 1 to 4 m tall, with strongly angled twigs and bright green stems.

The flowers are greenish to pinkish, and the blossoms are solitary in the axils of the lowest leaves of the youngest shoots. The fruit is a berry that is bright red.

Red whortleberry

Vacciniaceae

Vaccinium vitis-idaea L. Other common names include Cowberry, Lingonberry and Mountain Cranberry. There are two varieties: *V. vitis-idaea* var. *vitis-idaea* L. from Eurasia and *V. vitis-idaea* var. *minus* Lodd. from North America. *V. vitis-idaea* is native to the British Isles and most of the cooler parts of the northern hemisphere. The blueberry (*V. corymbosum*) is also sometimes called the whortleberry. The fruit is a globose berry up to 8–10 mm in diameter and is red in colour and produced on evergreen shrubs some 15–30 cm high.

Harvest maturity is judged on colour change of the skin and they are picked by hand. At room temperature of 20 °C and 60% r.h. they could be kept for 5–7 days and at 0 °C and 90% r.h. for 3–4 weeks (Mercantilia 1989).

Rhubarb

Polygonaceae

Rheum rhabarbarum L. It is a perennial herb and the edible portion is the leaf stalks or petioles, which are normally red but green ones are also produced. They are used as a stewed fruit or in pies. In Britain it can be grown in the conventional way in the field or by harvesting the rootstocks in autumn and growing them in the dark in heated sheds over-winter. When grown this way it is called forced rhubarb and is earlier, more tender and less acid than those grown conventionally in the open. The rhubarb triangle in West Yorkshire in Britain is famous for forced rhubarb. The rhubarb triangle was originally referred to as an *area* among *Leeds*, *Bradford* and *Wakefield* but even at that time, in the 1940s and 1950s from personal observations, there were certainly many growers in Halifax in the 1950s that are not there now. It is now more commonly referred to as among *Wakefield*, *Morley* and *Rothwell*. The chemical content was given by USDA (2012) in Table 174.

Table 174 The composition of rhubarb for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	93.61 g	Thiamine	0.020 mg
Energy	21 kcal	Riboflavin	0.030 mg
Protein	0.90 g	Niacin	0.300 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.024 mg
Carbohydrate, by difference	4.54 g	Folate	7 µg DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Total sugars	1.10 g	Vitamin A	5 µg RAE
Calcium	86 mg	Vitamin A	102 IU
Iron	0.22 mg	Vitamin E	0.27 mg
		(α-tocopherol)	
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	14 mg	Vitamin D	0 IU
Potassium	288 mg	Vitamin K	29.3 µg
		(phylloquinone)	
Sodium	4 mg	Fatty acids, total saturated	0.053 g
		Fatty acids, total monounsaturated	0.039 g
Zinc	0.10 mg	Fatty acids, total polyunsaturated	0.099 g
Total ascorbic acid	8.0 mg		

Harvesting

Harvest time is when they are large enough for the market, but before they become tough and bitter. The method used is pulling the leaf stalks so that they come away cleanly from the root stock and trimming off the leaves. Sibley and Rifai (2005) described a rhubarb harvester using elevating conveyors transversely mounted to a flat-bed trailer having double-direction trimming stations placed on its deck. The productivity using the harvesting aid averaged 53.4 kg person⁻¹ h⁻¹ compared to 40.7 kg person⁻¹ h⁻¹ for hand harvesting and the workers indicated that they were happier working with the harvesting aid compared to hand harvesting.

Precooling

Forced-air cooling with high humidity was the most suitable, vacuum cooling and air cooling in a conventional cold store was also suitable and hydrocooling was generally unsuitable (MAFF n.d.).

Postharvest physiology

Since it is not a fruit in the botanical sense it is non-climacteric. Their respiration rate was given in Table 175.

Table 175 Respiration rate of rhubarb at different temperatures (source: adapted from Maynard 2002)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	9–13
5	11–18
10	25
15	31–48
20	40–57

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 2 days. Rhubarb will freeze at about –2.5 to –1.5 °C (Wright 1942). Refrigerated storage recommendations include

- 0 °C and 90% r.h. for 2–3 weeks (Anonymous 1967);
- 0 °C and 90–95% r.h. for 2–3 weeks (Phillips and Armstrong 1967);
- 0–1 °C and 90–95% r.h. for up to 21 days (Tindall 1983);
- 10 °C for about 7 days (Tindall 1983);
- 0 °C and 90–95% r.h. for 20 days (Mercantilia 1989);
- 4 °C for 12 days (Mercantilia 1989);
- 8 °C for 8 days (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 2–4 weeks (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 14–21 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1990);
- 0 °C and 95–100% r.h. for 2–4 weeks (Maynard 2002).

Modified atmosphere packaging

Unsealed polyethylene film liners in crates reduced their weight loss (Lutz and Hardenburg 1968), but there is no evidence that they increased their postharvest life.

Diseases

Postharvest diseases include anthracnose (*Colletotrichum erumpens*) that causes oval, soft, watery lesions on petioles. Bacterial soft rot (*Pseudomonas*

marginalis and *Erwinia caratovra*) causes a soft, slimy decay. Grey mould (*Botrytis cinerea*) causes soft, brown lesions on petioles (Snowdon 1992, Maynard 2002).

Rose apple

Myrtaceae

Eugenia jambos L. synonymous with *Syzygium jambos* Alston, also called pommarosa.

It is a native of the East Indies where it is also used as an ornamental tree. It is a tropical tree up to about 9 m high with glossy leathery leaves. The edible portion is the fruit, which is a berry with a persistent calyx, oval or globular in shape and up to 5 cm long. The skin is white or yellow in colour with a faint pinkish blush. The pulp is rose scented, crisp, juicy, sweet and pale yellow in colour with a central cavity containing up to three seeds. The chemical content was given by USDA (2012) in Table 176. No information is available on storage, but it is related to the Malay apple (*E. malacensis*) and may well have similar storage characteristics.

Rowal

Flacourtiaceae, Salicaceae

Pangium edule Reinw. Other common names include keluak, keluwak and kepayang. It is a tall tree native to the mangrove swamps of Southeast Asia. It produces a large poisonous fruit with a reported cyanide content of $1834 \mu\text{g g}^{-1}$, which can be made edible by fermentation. The chemical content was given by USDA (2012) in Table 177.

Table 176 The composition of rose apple fruit for 100 g^{-1} fresh weight (source: adapted from USDA 2012)

Water	93.00 g	Potassium	123 mg
Energy	25 kcal	Sodium	0 mg
Protein	0.60 g	Zinc	0.06 mg
Total lipid (fat)	0.30 g	Total ascorbic acid	22.3 mg
Carbohydrate, by difference	5.70 g	Thiamine	0.020 mg
Calcium	29 mg	Riboflavin	0.030 mg
Iron	0.07 mg	Niacin	0.800 mg
Magnesium	5 mg	Vitamin B-12	0.00 μg
Phosphorus	8 mg	Vitamin A	17 μg RAE
		Vitamin A	339 IU

Table 177 The composition of rowal fruit for 100 g^{-1} fresh weight (source: adapted from USDA 2012)

Water	71.40 g	Magnesium	32 mg
Energy	111 kcal	Phosphorus	52 mg
Protein	2.30 g	Potassium	131 mg
Total lipid (fat)	2.00 g	Sodium	4 mg
Carbohydrate, by difference	23.90 g	Zinc	0.43 mg
Total dietary fibre	6.2 g	Total ascorbic acid	25.8 mg
Total sugars	14.10 g	Vitamin A	19 μg RAE
Calcium	15 mg	Vitamin A	383 IU
Iron	2.20 mg	Fatty acids, total saturated	0.245 g

Salak

Arecaceae, Palmae

Salacca edulis Reinw., *S. glabrescens* Griff., *S. zalacca* Gaertner Voss, *S. ramosiana*, *Calamus zalacca*. Other common names include snake fruit and sala. They are native to Brunei, Indonesia and Malaysia and are also found in Thailand, Cambodia, Myanmar, Vietnam, Philippines and China. They are cultivated throughout Indonesia, and there are at least 30 cultivars and two popular ones are Pondoh and Bali (Supriyadi *et al.* 2003). In Malaysia four cultivars of salak were called SS1, SS2, SS3 and SS4 by the Sabah State Agriculture Department (Aralas *et al.* 2009). In Indonesia they are said to give more mature women desirable characteristics. They are very short stemmed palms, with leaves that have a spiny petiole and are up to 8 m long. The fruits are globose in shape up to 10 cm long and with a reddish brown skin with appressed imbricate snake skin like scales (Figure 118), which account for one of the common names. The creamy flesh is the edible part and is divided into four segments each containing a large brown globular seed up to 3 cm in diameter. They have a sweet sour flavour with a slight taste of apple (Purseglove 1968).

Supriyadi *et al.* (2003) detected 10 compounds, including two carboxylic acids, six methyl esters, an alcohol and a furaneol (2,5-dimethyl-4-hydroxy-3(2H)-furanone) as the most characteristic odorants. Methyl esters exhibited particularly sweet and fruity odour characteristics in snake fruit at more mature stages, whereas carboxylic acids exhibited the sweaty odour that tends to prevent non-native consumers from liking the fruit. Aralas



Figure 118 Salak fruit in a market in Thailand. See colour plate section.

et al. (2009) showed that the total phenolic and flavonoid contents of samples from Malaysia were in the range 12.6–15.0 mg g⁻¹ gallic acid equivalent and 4.9–7.1 mg g⁻¹ catechin on a dry matter basis. The antioxidant activities of the extracts were highly correlated with total phenolic and moderately correlated with flavonoid content. The reducing capabilities of the extracts were moderately correlated with all phytochemicals tested.

Harvesting

Supapvanich and Megia (2011) reported that basically optimum harvest maturity is judged to be when the skin colour changes to a blackish brown. At that time the seed also turns black or blackish brown. They also mentioned optimum harvest maturity when the fruits were 37–39 weeks after pollination for the cultivar Sala and 28–30 weeks for the cultivar Rakam and Mahendra and Janes (1993) harvested fruit some 6 months after flowering. Both an electronic nose equipped with 18 sensors and fingerprint mass spectrometry appeared to discriminate efficiently between the fruits at different maturation stages (Supriyadi *et al.* 2003).

Postharvest physiology

Supapvanich and Megia (2011) reported that it was not clear whether or not salak was a climacteric fruit. They cited some evidence that showed a rise in postharvest respiration rate 3 days after harvest with a concomitant increase in ethylene production, both of which then declined.

Storage

In tropical ambient temperatures the skin will split within a few days (Purseglove 1968). However, Mahendra and Janes (1993) contradicted this and found that they could be stored at 29–32 °C for 9 days and 22–24 °C for 10 days and Sukewijaya *et al.* (2003) for 5–10 days at 29 °C. Refrigerated storage recommendations were 3–5 °C for 25 days with symptoms of slight chilling injury beginning after 3 days, 7–10 °C for 23 days with symptoms of slight chilling injury beginning after 4 days and 15 °C for 13 days (Mahendra and Janes 1993).

Diseases

Sukewijaya *et al.* (2003) reported that the fungal pathogens of the fruit included *Caratocystis paradoxa*, *Fusarium* sp. and *Aspergillus* sp.

Sansapote

Chrysobalanaceae

Licania platypus (Hemsl.) Fritsch, synonymous with *Moquilea platypus* Hemsl. Other common names include licania, sonzapote and sunsapote.

It is a tropical species limited to elevations up to about 600 m and it grows wild in dense forests from southern Mexico to Panama, on both coasts and in northern Colombia.

The tree grows up to 50 m in height with a rounded crown of thick branches and dark purplish or brown bark dotted with tiny white or reddish-white lenticels. The flowers are small and fragrant. The fruit are obovoid or pyriform 13–20 cm long and 10–14 cm wide with a thin, dark-brown or reddish, warty skin covered with white lenticels. The flesh is yellow or orange-yellow, soft, fibrous, dry or juicy and of subacid or sweet flavour. Usually there is a single flattened seed 6–10 cm long.

Santol

Meliaceae

Sandoricum koetjape (Burm.f.) Merr. synonymous with *S. indicum* Cav., *S. nervosum* Blume and *Melia koetjape* Burm. f. There are two general types of santol: yellow (formerly *S. indicum* or *S. nervosum*)

and the red (formerly *S. koetjape*) (Morton 1987). It is also called sour apple or *cotton fruit*.

The santol is believed native to be former Indochina (especially Cambodia and Southern Laos) and peninsular Malaysia and to have been introduced into India, the Andaman Islands Borneo, Indonesia, the Moluccas, Mauritius, and the Philippines where it has become naturalized. The santol is tropical and cannot be grown above 1000 m in Java and flourishes in dry as well as moist areas of the Philippine lowlands. The land areas used for cultivation santol trees in Thailand were increasing and scattering continually. Land areas under production reached a figure of 5471 ha in 2006 (Morton 1987).

It is a popular fruit in Thailand, which is eaten fresh and also processed into various products including pickled santol fruits, santol in syrup, dressed salad and oven-dried crispy santol slices. In India, it is eaten with spices. With the seeds removed, it is made into jam or jelly. Pared and quartered, it is cooked in syrup and preserved in jars. Young fruits are candied in Malaysia by paring, removing the seeds, boiling in water and then boiling a second time with sugar. In the Philippines, they are peeled then cut open, the seeds removed and commercially preserved in syrup or made into marmalade. Ripe fruits may be fermented with rice to make an alcoholic drink (Morton 1987, Chutichudet *et al.* 2008).

It is a fast-growing, straight-trunked, pale-barked tree 15–45 m high, branched close to the ground and buttressed when old. The flowers are greenish, yellowish or pinkish-yellow borne on the young branchlets in loose, stalked panicles up to 15–30 cm long. The fruit is a globose or oblate capsule, with wrinkles extending a short distance from the base; 4–7.5 cm wide; yellowish to golden, sometimes blushed with pink. The edible downy peel may be thin or thick with a thin, milky juice. The edible white, translucent, juicy aril is sweet, subacid or sour, surrounding 3–5 brown, inedible seeds that are up to 2 cm long, tightly clinging or sometimes free from the pulp.

Browning of the fruit occurred very rapidly during various processes of cutting, slicing or peeling. Chutichudet *et al.* (2007) found that the level of the browning oxidative reaction appearance on peel, flesh and seed and was caused by the enzyme activity of 1,2-benzene diol, oxygen oxidoreductase (polyphenol oxidase, PPO). Chutichudet (2001) reported that browning reaction might also be due to

Table 178 The composition of santol fruit for 100 g⁻¹ fresh weight (source: Morton 1987)

	Yellow	Red	Unspecified type
Moisture	87.0 g	83.1–85.5%	85.4 g
Protein	0.118 g	0.89%	0.06 g
Carbohydrates	—	11.43%	—
Fat	0.10 g	1.43%	0.52 g
Fibre	0.1 g	2.30%	1.26 g
Ash	0.31 g	0.65–0.88%	0.39 g
Calcium	4.3 mg	0.01%	5.38 mg
Phosphorus	17.4 mg	0.03%	12.57 mg
Iron	0.42 mg	0.002%	0.86 mg
Carotene	0.003 mg	—	—
Thiamine	0.045 mg	0.037 mg	—
Niacin	0.741 mg	0.016 mg	—
Ascorbic acid	86.0 mg	0.78 mg	—

non-enzymatic reaction from amino acid and sugar. Sangkitikomol (2000) found that santol fruits contain the total antioxidants which protect several diseases including rickets, arthritis, heart disease, paralysis and cancer. Morton (1987) gave the composition of yellow, thick-skinned, acid fruits in Honduras, red type from the Philippines and an unspecified type from India (Table 178). The pericarp contained glucose, sucrose, malic acid, tartaric acid and much pectin.

Harvesting and handling

Siriphanich *et al.* (2008) reported that it is a climacteric fruit having a distinct climacteric rise in respiration rate and ethylene production. The fruit should be harvested when fully yellow or red in colour, which is still in the pre-climacteric stage, in order to obtain its best eating quality. Chutichudet (2001) reported that inappropriate harvesting or postharvest handling practices results in bruising and wounding of epidermal cells causing browning.

Storage

After harvest, the peel's firmness and TA decreased while TSS increased moderately. However, TSS and TA of the aril were rather stable. Storage at above 14 °C was recommended to avoid chilling injury for about 3 weeks. Chilling injury symptoms were browning of the skin and the inner peel portion and translucency of the aril (Siriphanich *et al.* 2008).



Figure 119 Sapodillas showing the correct harvest maturity and the internal structure.

Sapodillas

Sapotaceae

Manilkara achras, (Mill.) Fosberg synonymous with *Achras sapota*, L. *M. zapotilla* (Jacq.) Gilly. Other common names include sapota, zapota, chico chiku and chiku.

It is a native of Central America and was cultivated in the West Indies in pre-Colombian times and was considered by Oviedo in 1513–1525 as the best of all fruits. It was taken by the Spanish to the Philippines and spread westward to Malaysia (Purseglove 1975).

Chicle, which is used in making chewing gum, is obtained from the latex of the tree. Trees are tapped, like rubber trees, every 2 or 3 years and the latex contains some 20–40% chicle. Chicle was said to have been used by the Aztecs as chewing gum (Purseglove 1968). In India application of calcium to trees was found to improve their postharvest characteristics (Lakshmana and Reddy 1995).

It is an evergreen forest tree up to 20 m high. Fruits are globose to ovoid and up to 10 cm in diameter with a thin rusty brown to greyish skin. The pulp is yellowish brown and can have from 0 to 12 hard black seeds, which are easily separated from the pulp (Figure 119). The chemical content was given by USDA (2012) in Table 179.

Harvesting

In India the cultivar Kalipatta exhibited a double sigmoid pattern of growth and took 42 weeks from

Table 179 The composition of sapodilla fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	78.00 g	Zinc	0.10 mg
Energy	83 kcal	Total ascorbic acid	14.7 mg
Protein	0.44 g	Thiamine	0.000 mg
Total lipid (fat)	1.10 g	Riboflavin	0.020 mg
Carbohydrate, by difference	19.96 g	Niacin	0.200 mg
Total dietary fibre	5.3 g	Vitamin B-6	0.037 mg
Calcium	21 mg	Folate	14 µg DFE
Iron	0.80 mg	Vitamin B-12	0.00 µg
Magnesium	12 mg	Vitamin A	3 µg RAE
Phosphorus	12 mg	Vitamin A	60 IU
Potassium	193 mg	Fatty acids, total saturated	0.194 g
Sodium	12 mg	Fatty acids, total monounsaturated	0.521 g
		Fatty acids, total polyunsaturated	0.011 g

Table 180 Effects of harvest maturity and storage temperature on the mean storage life, or the maximum time that they can be held and still ripen normally, of Philippines sapodillas (source: adapted from Campo 1934)

Harvest maturity	Storage temperature (°C)				
	0	10	15	20	27.5
Green	5.6	8.4	18.0	12.0	6.6
Turning	6.4	11.0	16.4	10.4	5.4
Ripe	12.6	8.4	5.8	4.2	2.0

fruit set to attain harvest maturity (Rao *et al.* 1995). The skin of the fruits changes colour from green to brown as they mature. Harvest maturity is usually determined on the colour of the skin (Table 180). Baez *et al.* (1998) showed that at harvest, the fruits should have 13.2 °Brix, 0.24% TA and a firmness of 64.6 N. Fruit weight loss after 6 days at 20 °C reached 5.1%, while firmness dropped to 1.9 N. However, soluble solids content increased to 25.8 °Brix and TA did not show any significant changes during storage. Pulp colour ranged from white cream at harvest to light orange after 6 days at 20 °C.

Postharvest treatment

Wardlaw (1937) reported that after harvesting, fully grown but unripe fruits could be placed in an atmosphere containing high levels of CO₂ to

remove astringency. Treatment of fruit with Ethrel at 1–3 mL L⁻¹ accelerated ripening and reduced their pectin, phenolics, TSS, sugar and vitamin C content (Ingle *et al.* 1982). Pre-harvest sprays of isopropyl *n*-phenylcarbamate at 100 µL L⁻¹ retarded respiration, but maleic hydrazide at 0.5–1.0 mL L⁻¹ accelerated it (Lakshminarayana and Subramanyam 1966). However, legislation exists in some countries on the application of these chemicals. Fruit waxed with a fatty acid sucrose ester could be stored for 40 days at 10 °C (Salunkhe and Desai 1984).

In Brazil fruits treated with 300 nL L⁻¹ 1-MCP for 12 h and then stored in MA packaging at 25 ± 2 °C and 70 ± 5% r.h. had delayed softening for 11 days longer than those not treated (Morais *et al.* 2008). In Mexico treatment with 100 or 300 nL L⁻¹ 1-MCP resulted in a storage life of 38 days at 14 °C (Arevalo-Galarza *et al.* 2007). 1-MCP treatment at 40 or 80 nL L⁻¹ for 24 h at 20 °C delayed the increases in respiration rate, ethylene production and resulted in increased polygalacturonase activity by 6 days during storage at 20 °C. Decreases in ascorbic acid, TSS, TA and chlorophyll content were also delayed (Zhong *et al.* 2006). 1-MCP-treated fruit showed an inhibition of cell wall degrading enzyme activities and less extensive solubilization of polyuronides, hemicellulose and free neutral sugar when compared to non-treated fruit. It was suggested that delayed softening of sapodilla is largely dependent on control of ethylene biosynthesis (Morais *et al.* 2008).

Postharvest physiology

Guadarrama *et al.* (2000) found fruit to be climacteric in storage at 22–28 °C. In studies in Mexico fruits were also found to be climacteric and reached their respiratory peak of 27 mL CO₂ kg⁻¹ h⁻¹ at 20 °C and 85% r.h. after 6 days (Baez *et al.* 1998). The ethylene peak preceded the rise in respiration by 1 day with maximum production of 1.7 µL kg⁻¹ h⁻¹. Broughton and Wong (1979) also found that fruits to be climacteric with the respiratory peak occurring at the same time as, or 1–2 days after, peak ethylene production. They also found that ascorbic acid and glucose levels increased with ripening but ascorbic acid decreased when the fruit became over ripe. Ethylene production was 2.8 at 15 °C, 3.7 at 20 °C and 6.1 µL kg⁻¹ h⁻¹ at 25 °C (Broughton and Wong 1979, Lakshminarayana

1980). Lakshminarayana and Subramanyam (1966) working in India had previously reported that it to be a climacteric fruit, but it did not reach the climacteric peak while on the tree. They gave their respiration rate at 24–28 °C as 16 mg (9 µL) CO₂ kg⁻¹ h⁻¹.

Storage

At room temperature and fruits could not be kept beyond 8 days in ambient conditions (Flores and Rivas 1975). The cultivar Kalipatti was stored at room temperature of 31.7–36.9 °C and 23–35% r.h. or in an evaporatively cooled chamber at 20.2–25.6 °C and 91–95% r.h. in India by Waskar *et al.* (1999). The rate of change of physicochemical constituents was slower in fruits stored in a cool chamber than in fruits stored at room temperature. SeaLand (1991) differentiated between sapote, for which they recommended 12.2 °C and 85–90% r.h. and sapodilla, for which they recommended 15.6 °C and 85–90% r.h. both for 14–21 days. Storage below 1.7 °C resulted in chilling injury but not at 1.7–3.3 °C (Singh and Mathur 1954). However, later workers have found chilling injury during storage at much higher temperatures. Fruits stored for 28 days at 10 °C failed to ripen properly indicating chilling injury (Abdul-Karim *et al.* 1993). Fruits stored at 5 °C developed chilling injury and they failed to ripen properly even after 3 days at room temperature (Mohamed *et al.* 1996), but they found that chilling injury was observed in non-wrapped fruits but not in fruits sealed in 0.05 mm LDPE film bags at 5 °C. Broughton and Wong (1979) and Salunkhe and Desai (1984) found that chilling injury occurred in fruit stored for 21 days at 10 °C and storage at 6–10 °C caused irreversible damage and resulted in poor flavour. Other storage recommendations include

- 4.4–10 °C in India (Wardlaw 1937);
- 7.2–10 °C for 16 days then 2–3 days at 27–34 °C in Jamaica, but when these conditions were tried in Trinidad the fruits failed to ripen normally (Wardlaw 1937);
- 1.7–3.3 °C for 8 weeks in India (Singh and Mathur 1954);
- 12 °C for up to 24 days (Flores and Rivas 1975);
- 20 °C, but short-term holding of the fruit at lower temperatures was also possible (Broughton and Wong 1979);

- 19.4–21.1 and 85–90% r.h. for 2.5 weeks with 12% loss for turning fruit (Pantastico 1975);
- 0–2.2 °C and 85–90% r.h. for 2 weeks for ripe fruit (Pantastico 1975);
- 20 °C and 90% r.h. for 2–3 weeks for turning fruit (Snowdon 1990);
- 0 °C and 90% r.h. for 2 weeks for ripe fruit (Snowdon 1990);
- 10 °C for 21 days for the variety Jantung (Abdul-Karim *et al.* 1993);
- 15 °C for 16 days for the variety Jantung (Abdul-Karim *et al.* 1993);
- 20 °C for 10 days for the variety Jantung (Abdul-Karim *et al.* 1993).

Controlled atmosphere storage

There is little information in the literature on controlled atmosphere storage, but Broughton and Wong (1979) recommended 20 °C with 5–10% CO₂ and complete removal of ethylene from the storage atmosphere. High concentrations of CO₂ or extreme humidities impaired the quality of stored fruits (Broughton and Wong 1979).

Modified atmosphere packaging

The fruits could be stored in 25-µm-thick PE film bags with 1.2% vents at room temperature for up to 9 days and 13–15 days in a cool chamber (Waskar *et al.* 1999). Packaging in sealed 0.05 mm LDPE film bags, with two fruits per 10 × 15 cm bag, or sealed double-layered 0.05 mm LDPE film bags, with two fruits per 10 × 15 cm bag, or vacuum-packed in 0.05 mm LDPE film or shrink wrapped in 0.025 mm PVC (under a hot-air tunnel at 150 °C for 20 s) generally increased storage life to 4 weeks at 10 °C and 3 weeks at 15 °C (Mohamed *et al.* 1996). They also found that fruit texture was maintained best in LDPE film packaging and these fruits had the highest sensory scores for taste, colour, texture and overall acceptability. Ascorbic acid content was highest in vacuum-packed fruits followed by low-density polyethylene film-packaged fruits. The heating involved in shrink wrapping had deleterious effects on storage life. Non-wrapped fruits had the highest percentage of infected fruits and vacuum-packed fruits had the lowest; there was no difference in spoilage between the two LDPE films.

Ripening

Ripening was not affected by treatment with O₂, ethylene or indole acetic acid (Broughton and Wong 1979). Guadarrama *et al.* (2000) ripened the cultivars Prolific and Martin grown in Venezuela at 22–28 °C and 60–70% r.h. They found that the total chlorophyll, tannins, total carotenoids and TSS decreased and softening increased, although the postharvest patterns were different in each cultivar.

Disease

Phytophthora palmivora and species of *Pestalotiopsis* and *Phomopsis* can cause fruit rot (Snowdon 1990).

Sapote

Sapote is a common name used for many tropical fruit including *Pouteria sapota* (Jacq.) H.E. Moore & Stearn, synonymous with *Colocarpum sapota* (Jacq., Merr., *C. mammosum*, Pierre., *Achras mammosa* L., *Lucuma mammosa*, Gaertn., *Vitellaria mammosa*, Radlk. and *Achradelpha mammosa*, Cook. Also the names *P. mammosa* (L.) Cronquist, *Lucuma mammosa* Gaertn., *Achradelpha mammosa* Cook have been used. They are also called Sapote, Zapote, Mamey, Mamey Colorado, Mamey Sapote, Chico-Mamey, Marmalade-Fruit, Marmalade-Plum and Grosse Sapote. Morton (1987) commented that the word sapote is believed to have been derived from the Aztec name tzapotl, a general term applied to all soft, sweet fruits. It has long been utilized as a common name for *Pouteria sapota* (Jacq.) H.E. Moore & Stearn (synonymous with *P. mammosa* (L.) Cronquist, *Lucuma mammosa* Gaertn., *Achradelpha mammosa* Cook, *Vitellaria mammosa* Radlk., *Calocarpum mammosum* Pierre, *C. sapota* Merrill, *Sideroxylon sapota* Jacq.). Alternate vernacular names include sapota, zapote, zapote colorado, zapote mamey, lava-zapote, zapotillo, mamey sapote, mamee sapote, mamee zapote, mamey colorado, mamey rojo, mamee or mamee apple or red sapote. In El Salvador, it is known as zapote grande, in Colombia as zapote de carne; in Cuba, it is mamey, which tends to confuse it with *Mammea americana* L., a quite different fruit widely known by that name. The usual name in Panama is mamey de la tierra; in Haiti, sapotier jaune d'oeuf or grand sapotillier; in Guadeloupe,

sapote à creme; in Martinique, grosse sapote; in Jamaica, it is marmalade fruit or marmalade plum; in Nicaragua, it may be called guaicume; in Mexico, chachaas or chachalhaas or tezonzapote and in Malaya and the Philippines, chico-mamei or chico-mamey. The sapodilla (*Manilkara zapota* van Royen) which has also been called sapote, zapote or zapote chico to distinguish it from the larger fruit. *Pouteria sapota* occurs naturally at low elevations from southern Mexico to northern Nicaragua. It is much cultivated and possibly also naturalized up to 600 m and occasionally found up to 1500 m throughout Central America and tropical South America. It is abundant in Guatemala. In the West Indies, it is planted to a limited extent from Trinidad to Guadeloupe, and in Puerto Rico, Haiti and Jamaica, but mainly in Cuba where it is often grown in home gardens and along streets and for shading coffee because it loses its leaves at the period when coffee plants need sun, and the fruit is extremely popular. It is grown only occasionally in Colombia, Ecuador, Venezuela and Brazil. It was introduced into the Philippines by the early Spaniards but is grown only around Cavite and Laguna on Luzon and Cagayan on Mindanao. From the Philippines, it was carried to southern Vietnam where the fruit is eaten when very ripe.

Sapote mamey

Sapotaceae

Calocarpum sapota (Jacq.) Merr. synonymous with *C. mammosum* (L.) Pierre, *Lacuma mammosa* Gaertn., also called Mamey Zapote. The common name sapote is used for many tropical fruits. The fruit are ovoid or ellipsoid and can be up to 15 cm long. The skin has a roughened and scurfy surface and the flesh is somewhat granular and red to reddish brown in colour with a rich sweet flavour.

Hot water treatment

In hot water treatment at 60 °C the centre of a 500 g fruit took about 45 min to reach the water temperature. Once the centre of the fruit reached the water temperature, they were held for an additional 60 min in the water. After immersion, fruits were allowed to dry and were held in storage at 25 °C for

4–6 days. Hot water treatment had relatively minor effects on fruit quality and may have potential as an insect disinfestation treatment. Judges gave a higher score for the flesh colour of fruits treated at 60 °C compared with those of untreated fruits as there was less flesh browning and they had firmer flesh (Diaz Perez *et al.* 2000).

Gibberellic acid

Patel and Katrodia (1998) reported that treatment of sapodilla fruits with 150 ppm gibberellic acid significantly delayed ripening and improved shelf life compared with the untreated controls.

Storage

In Mexico storage of fruits at 2.5 °C showed abnormal ripening with partial browning of the flesh near to the skin, indicating chilling injury (Diaz Perez *et al.* 2000). Fruits stored at 10 or 15 °C and then ripened at 20 °C had portions of the flesh with a much higher firmness and poorer development of red colour compared to other parts of the fruit. This uneven ripening was probably a result of chilling injury. The number of fruits with injury was higher at 10 °C than at 15 °C and increased with storage time (Diaz Perez *et al.* 2000).

Ripening

Ripening was associated with flesh softening, an increase in soluble solids content and a change in flesh colour from yellow or pale pink to a dark pink or red. No changes in fruit skin colour or in flesh acidity were observed as ripening progressed. Ripe fruits had 30% or higher soluble solids content, orange or red flesh, acidity of 6–8 mM H⁺, and flesh firmness (compression force) 50 N. The flesh turned brown in overripe fruits (Perez Tello *et al.* 1999). Diaz Perez *et al.* (2000) found that temperature affected their speed of ripening as follows:

- 27 °C ripened in 3 1/2 days after harvest;
- 25 °C ripened in 5 days after harvest;
- 20 °C ripened in 7 days after harvest.

At 10 °C fruits showed minor changes in colour and firmness and a slow rate of soluble solids increase.

Satsuma

Rutaceae

Citrus reticulata Blanco, *C. unshiu* (Swingle) Marcow. Other common names include Mandarin, Seedless Mandarin, Satsuma Mandarin, Satsuma Orange and Tangerine. Satsuma probably originated from the former Satsuma Province in Japan, from which they were taken to China and fruits were first exported from there to the west.

The tree is cold hardy and produces sweet and usually seedless fruit about the size of other mandarin oranges (*C. reticulata*). The peel, which is thin and leathery dotted with large and prominent oil glands, is lightly attached around the fruit, enabling it to be peeled very easily in comparison to other citrus fruits. Satsumas also have delicate flesh that cannot withstand the effects of careless handling and bruising and damage to the fruit may not be immediately apparent on cursory visual inspection. The fruit is a berry or hesperidium, which is a non-climacteric. It is oblate to obovate in shape and large compared to other mandarin types. It has course peel, often with internal colour developing before peel colour, and they have a moderately hollow axis and are usually seedless. Fruits produced under cool conditions tend to have a deep orange peel colour. These are produced in the cool subtropical areas of Japan, Central China, Spain and South Africa (Davies and Albrigo 1994) and will freeze at about -2.3 to -1.8°C (Wright 1942).

Harvesting

Harvest maturity is usually judged on colour change of the skin to a deep orange colour. Delayed light emission is a technique that has been used on Satsumas to grade by maturity based on chlorophyll content (Chuma *et al.* 1977). The fruit is subjected to a bright light and then placed in darkness where a sensor measures the amount of light emitted. A portable easy to use instrument was developed from this work although at this time it does not appear to be commercially available. Harvesting is by hand, usually clipping the fruit stalk.

Storage

Refrigerated storage recommendations include

- 0°C for 3–6 weeks then $6-8^{\circ}\text{C}$ for 6 weeks in Australia for Wickson, Satsuma, Golden Gage and President (Fidler 1963);
- 4°C and 85–90% r.h. for 8–12 weeks (Mercantilia 1989);
- 3.9°C and 85–90% r.h. for 56–84 days (SeaLand 1991);

Degreening

Optimum temperatures range between 25 and 29°C and humidity as high as possible, generally between 90 and 95% r.h. with ethylene at between 1 and $10\mu\text{L L}^{-1}$ for 24–72 h. The cultivar and the stage of maturity at harvest should be taken into account. Mayuoni *et al.* (2012) found that ethylene degreening had no effect on juice TSS and acid contents, and had only minor effects on contents and composition of juice aroma volatiles in the satsuma mandarins. Also sensory analysis tests showed that ethylene marginally impaired sensory acceptability, but this could be attributed, at least partially, to storage of the fruit for 5 days at 20°C before analysis.

Physiological disorders

Pantastico (1975) referred to as *Zebra Skin*, which form dark sunken areas that follow the divisions between the fruit segments. Incidence appears to be related to rough handling, heavy irrigation during production, prolonged degreening, high ethylene levels during degreening or in fully coloured fruit mixed with green ones during degreening.

Seville orange

Rutaceae

Citrus aurantium L., also called Bitter Orange. It originated in southern Asia, probably India, and it is likely that it was brought to Spain during Moorish times. Natives of the South Sea Islands, especially Fiji, Samoa and Guam, believe the tree to have been brought to their shores in prehistoric times. Arabs are thought to have carried it to Arabia in the 9th century. It was reported to be growing in Sicily in 1000 CE, and it was cultivated around Seville, Spain,

at the end of the 12th century. For 500 years, it was the only orange in Europe and it was the first orange to reach the New World. It was naturalized in Mexico by 1568 and in Brazil by 1587, and not long after it was growing wild in the Cape Verde Islands, Bermuda, Jamaica, Puerto Rico and Barbados. Sir Walter Raleigh took sour orange seeds to England; they were planted in Surrey and the trees began bearing regular crops in 1595 but were killed by cold in 1739. Spaniards introduced the sour orange into St. Augustine, Florida. It was quickly adopted by the early settlers and local Indians and, by 1763, sour oranges were being exported from St. Augustine to England. Sour orange trees can still be found in 'Everglades hammocks' on the sites of former Indian dwellings. The first sweet orange budwood was grafted onto sour orange trees in pioneer dooryards and, from that time on, the sour orange became more widely grown as a rootstock in all citrus-producing areas of the world than for its fruit or other features. Today, the sour orange is found growing wild even in southern Georgia and from Mexico to Argentina (Morton 1987).

The evergreen tree grows up to 9 m in height. The flowers are fragrant borne singly or in small clusters in the leaf axils, and 5–12% of the flowers are male. The fruit is a berry or hesperidium and is a non-climacteric fruit. They have dark orange coloured peel that is thick and fleshy with large pores. The fruit has a distinct pleasant aromatic flavour and the peel is used for the production of liqueur. There are 10–12 segments containing strongly acid pulp and from a few to numerous seeds and the centre becomes hollow when the fruit has fully grown. The whole fruit is used for marmalade (Morton 1987). Their composition was given by Morton (1987) in Table 181.

Harvesting

They are picked by hand when the peel has turned from green to fully orange. Care must be taken in harvesting since the mature trees are quite high, up to 15 m and their stems are thorny.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept

Table 181 The composition of Seville orange fruit for 100 g⁻¹ fresh weight of edible portion for fruits from Guatemala and El Salvador (source: Morton 1987)

Calories	37–66	Calcium	18–50 mg
Moisture	83–89.2 g	Iron	0.2 mg
Protein	0.6–1.0 g	Phosphorus	12 mg
Fat	Trace to 0.1 g	Vitamin A	290 µg or 200 IU
Carbohydrates	9.7–15.2 g	Thiamine	100 µg
Fibre	0.4 g	Riboflavin	40 µg
Ash	0.5 g	Niacin	0.3 mg
		Ascorbic acid	45–90 mg

for 2–3 weeks. Refrigerated storage recommendations include 10 °C and 90% r.h. for 3 months (Mercantilia 1989) and 10 °C and 85–90% r.h. for 90 days (SeaLand 1991).

Shea butter tree

Sapotaceae

Vitellaria paradoxa C.F. Gaertn. F. synonymous with *Butyrospermum parkii* also called shea tree and shi tree. Ferris *et al.* (2001) reported that the West African trees were a subspecies *paradoxa* and the subspecies in East African was *nilotica*.

It is indigenous to tropical Africa including Mali, Cameroon, Congo, Côte d'Ivoire, Ghana, Guinea, Togo, Nigeria, Senegal, Sudan, Burkina Faso, Ethiopia, Benin, Niger and Uganda. This savanna belt is also called the shea belt among some traders (Ferris *et al.* 2001).

The value of the shea tree to the economy of Ghana became more significant in the 1970s when it was announced that its vegetable fat can be used in cocoa butter equivalent production. Along with five other species, the European Union has approved shea for use in the formulation of non-cocoa butter fats for chocolate production with up to 5% content by weight allowed. The USA Food and Drug Administration also considers shea butter to be edible and allocated them as 'Generally Recognized as Safe' (Moore 2008).

The tree starts bearing fruits when 10–15 years old and attains full production when it is about 20–30 years. The shea fruit resembles a large plum and consists of a thin, tart, nutritious pulp that surrounds a relatively large, oil-rich seed from which shea butter is extracted with 1 kg of fruit giving approximately 400 g of dry seeds.

Table 182 Fatty acid content of Shea butter tree (*Vitellaria paradoxa*) from African agro-forestry parklands (source: adapted from Maranz *et al.* 2004)

Fatty acid	Range
16:0 Palmitic	2.6–8.4
18:0 Stearic	25.6–50.2
18:1 Oleic	37.1–62.1
18:2 Linoleic	0.6–10.8
20:0 Arachidic	0.0–3.5

Shea butter is composed of five principal fatty acids (Table 182) dominated by stearic and oleic acids, which together account for perhaps 85–90% of the fatty acids (Maranz *et al.* (2004). The fatty acid proportion of West African shea butter was found to be more variable than Ugandan shea butter; the oleic content ranges from 37 to 55%. Variability can be high even locally and a tree that produces hard butter can be located right next to one that produces soft butter. Ferris *et al.* (2001) reported that the subspecies *paradoxa* exhibited the typical fatty acid profile of commercially available shea butter where stearic and oleic acids are almost in similar amounts, while the subspecies *nilotica* was characterized by higher levels of oleic acid, thus providing a better product for the cosmetic industry. Shea butter from Chad and Uganda showed the relatively higher amounts of oleic acids (57.8–68.0%) and lower amounts of stearic acid (22.5–28.9%) than the shea butters from West Africa such as Benin, Burkina Faso, Côte d'Ivoire, Mali and Nigeria with similar levels of stearic acid (31.1–46.8%) and oleic acid (39.3–47.5%). Samples from Mali contained 19% palmitic acid and 31.1% stearic acid (Table 183).

Maranz *et al.* (2003) found that the concentration of phenolics was highly linked to the level of environmental stress so that shea kernels from the

hottest and driest areas e.g. the lake Chad basin area and those from much cooler and wetter area of Guinea and Western Cameroon showed the highest amount of total catechins compared to the shea kernels from regions with moderate rainfall and temperature e.g. Burkina Faso. Tocopherol content, especially α -tocopherol, which is a dominant tocopherol of shea butter, was directly correlated with temperature. The concentration of α -tocopherol in shea butter from hot, dry areas (N'Djamena in Chad) was higher with $414 \mu\text{g g}^{-1}$ than those from cooler areas of northern Uganda where they were $29 \mu\text{g g}^{-1}$ (Maranz *et al.* 2004). Okullo *et al.* (2010) also analysed the mineral composition and reported that the fruit pulp contains significant and adequate amount crude proteins, crude fibre, Vitamin C and nutrients (Ca, K, Mg, Na and Fe) and is equivalent to other edible fruits such as mango and stated that it must therefore be promoted in human nutrition.

Diseases

Pseudofusicoccum sp., *Phomopsis* sp., *Phoma* sp. and *Pestalotiopsis* sp. were identified on shea fruits.

Sloe

Rosaceae

Prunus spinosa L. It is native to Europe, western Asia and northwest Africa. It is also naturalised in New Zealand and eastern North America.

Sloes are the fruit of the blackthorn deciduous shrub or tree that can grow up to 5 m tall, with blackish bark and dense, stiff, spiny branches. The hermaphroditic flowers are about 1.5 cm in diameter, with five creamy-white petals. The fruit are drupes and are probably climacteric and resemble a tiny plum with a bluish black skin covered with a slight bloom. The flesh is green and acidic with a very strongly astringent flavour when fresh. They are seen growing wild, particularly in hedgerows, throughout Europe and are astringent even when ripe and are used for jam, liqueurs, wine and to flavour gin.

They are harvested in autumn when they change colour from green to blue and are thought to be better if they are harvested after frost. Care must be taken in harvesting since they are borne on spiny shrubs.

Table 183 Percentage content of fatty acids in shea butter grown in different regions (source: adapted from Ferris *et al.* 2001)

Origin	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2
Burkina Faso	12.1	42.5	39.3	4.5
Mali	19	31.1	42.6	5.7
Nigeria	3.2	38.9	47.5	6.5
Uganda	6.5	26.4	59.3	6.2

Soncaya

Annonaceae

Annona purpurea Moc. & Sesse. synonymous with *A. manirote* HBK., *A. involucrata* Baill., *A. prestonii* Hemsl. It is native and common in coastal lowlands from southern Mexico to Panama, Colombia and Venezuela. The tree was introduced into the Philippines in the early 20th century, grew well but apparently did not set fruit for several years. It was in Puerto Rico, in 1918, and in St. Croix in 1930. It has grown well but borne poorly in Honduras.

The tree grows up to 6–10 m high, with short trunk up to 45 cm in diameter, and spreading branches. The flowers have a strong scent creamy white outside, purple inside. The fruit is ovoid or nearly round, 15–20 cm wide with hard, four-sided, conical protuberances, each tipped with a curved hook, and is coated overall with a brown felt. The pulp is aromatic, yellow or orange, soft, fibrous, of mild with an agreeable flavour with numerous seeds. The fruit carpels separate easily when ripe.

Sour cherry

Rosaceae

Prunus cerasus L. It may have been introduced to Italy from Pontus in Asia Minor by Lucullus about BCE 70 and introduced to Britain by the Romans in CE 46. It has become common in the wild in most temperate countries in the Northern Hemisphere. Morello is perhaps the best known sour cherry and *P. cerasus* hybridizes with sweet cherry (*P. avium*) and produces either red or black fruit and are commonly called royal cherries or dukes. The fruit is a non-climacteric drupe and is produced on large deciduous trees in temperate and cold climates. The chemical content was given by USDA (2012) in Table 184.

Storage

In experiments with the cultivar Shattenmorelle it was found that after 9 days at 0 °C in air and subsequent storage for 3 days at 20 °C the percentage of rotten fruits was 4% (Nabialek *et al.* 1999). Blue mould (*Penicillium expansum*) was identified as the main cause of rotting. They will freeze at about –2.4 to –1.9 °C (Wright 1942) and refrigerated storage recommendations include

- 0 °C for only a few days as they are said to be unsuitable for storage (Lutz and Hardenburg 1968);
- 0–1 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1990);
- –0.5 °C and 90–95% r.h. for 3–7 days (SeaLand 1991).

Controlled atmosphere storage

SeaLand (1991) recommended –1.1 with 10–12% CO₂ with 3–10% O₂. Nabialek *et al.* (1999) found that after 24 days at 2 °C in 10% CO₂ with 3% O₂ and subsequent storage for 3 days at 20 °C the percentage of rotten fruits was 3%. Elimination of CO₂ from the atmosphere resulted in the percentage of rotten fruit being increased to 21%. English Morello was stored at 2 °C in 25% CO₂ + 10% O₂, 15% CO₂ + 10% O₂, 5% CO₂ + 10% O₂ or air for 20 days by Wang and Vestrheim (2002). They found that decay was greatly reduced in 25% CO₂ + 10% O₂, which also gave the best colour and TA retention and the highest TSS content. For the cultivars, Crisana (Paddy) and Ionescu *et al.* (1978) recommended 0 °C in 5% CO₂ + 3% O₂ but for only 20 days which resulted in about 7% loss.

Table 184 The composition of sour cherry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	86.13 g	Thiamine	0.030 mg
Energy	50 kcal	Riboflavin	0.040 mg
Protein	1.00 g	Niacin	0.400 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.044 mg
Carbohydrate, by difference	12.18 g	Folate	8 µg DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Total sugars	8.49 g	Vitamin A	64 µg RAE
Calcium	16 mg	Vitamin A	1283 IU
Iron	0.32 mg	Vitamin E (α-tocopherol)	0.07 mg
Magnesium	9 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	15 mg	Vitamin D	0 IU
Potassium	173 mg	Vitamin K (phyloquinone)	2.1 µg
Sodium	3 mg	Fatty acids, total saturated	0.068 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.082 g
Total ascorbic acid	10.0 mg	Fatty acids, total polyunsaturated	0.090 g

Diseases

These are similar to those of sweet cherry.

Soursop

Annonaceae

Annona muricata L. Other common names include graviola and guanabana. It is a tropical fruit native to tropical America and the West Indies, although it is grown in other countries including Sri Lanka. It is a tree that produces a dark green spiny aggregate fruit made up of berries fused together with associated flower parts. The fruits are irregular in shape but generally ovoid and up to 25 cm long with white milky flesh full of hard black seeds (Figure 120). It is classified as a multiple climacteric fruit due to the berries that make up a single fruit being of different maturities and thus ripening at different times (Biale and Barcus 1970).

Cheong *et al.* (2010) found a total of 35 volatile compounds, comprising 19 esters, 6 alcohols, 3 terpenes, 2 acids, 2 aromatics, 2 ketones and an aldehyde in fruit. In the Cameroon Jirovetz *et al.*

(1998) identified more than 50 compounds where esters of aliphatic acids were especially dominating, with methyl 2-hexenoate, ethyl 2-hexenoate, methyl 2-octenoate and methyl 2-butenate as main compounds. Additional mono- and sesquiterpenes such as α -caryophyllene, 1,8-cineole, linalool, terpineol, linalyl propionate and calarene were highly concentrated in the essential oil of these fresh fruits. It has been reported that it cannot withstand low-temperature storage at any stage of maturity (Wardlaw 1937) and 10–15 °C and 90% r.h. for 1–2 weeks was recommended by Snowden (1990).

Spanish plum

Anacardiaceae

Spondias purpurea L. also called ciriguela, Jamaican plum and red mombin. It is widely found in the northern part of South America, northeast of Brazil and Central America and is native to the tropical dry forests of Mexico and Central America. The fruit is borne on a tropical tree and is oval in shape and up to 4 cm long with a reddish skin. It contains a large seed surrounded by a layer of watery, pleasantly sub-acid pungent pulp that is about 50% of the fruit.

Ceva-Antunes *et al.* (2006) identified 27 volatiles, especially ketones, alcohols, aldehydes, esters and terpene hydrocarbons with the preponderance of hexanal (10.6%), ethyl acetate (8.4%), 3-hexen-1-ol (6.8%), 2-hexen-1-ol (5%), trans-2-hexenal (5%) and hexyl acetate (2%). TSS increased from 7.7% at harvest at the mature green stage to 15.7% post-climacteric and there was a continuous decrease in ascorbic acid from 39.5 to 8.3 mg kg⁻¹ and chlorophyll while total carotenoids increased continuously during ripening (de Almeida Sampaio *et al.* 2008). The chemical content was given by USDA (2012) in Table 185.

Postharvest physiology

de Almeida Sampaio *et al.* (2008) found that they were climacteric and mature green fruit had a maximum CO₂ production of 111.8 ml kg⁻¹ h⁻¹ after 140 h and O₂ absorption of 124.2 ml kg⁻¹ h⁻¹ after 130 h after harvest.



Figure 120 Soursop fruit ready for harvest in Brazil.

Table 185 The composition of Spanish plum fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	81.16 g	Thiamine	0.070 mg
Energy	66 kcal	Riboflavin	0.050 mg
Protein	1.00 g	Niacin	0.900 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.059 mg
Carbohydrate, by difference	16.84 g	Folate	14 µg DFE
Total dietary fibre	3.3 g	Vitamin B-12	0.00 µg
Total sugars	13.54 g	Vitamin A	0 µg RAE
Calcium	14 mg	Vitamin A	2 IU
Iron	0.60 mg	Vitamin E (α-tocopherol)	0.08 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	27 mg	Vitamin D	0 IU
Potassium	278 mg	Vitamin K (phyloquinone)	0.4 µg
Sodium	14 mg	Fatty acids, total saturated	0.051 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.090 g
Total ascorbic acid	20.6 mg	Fatty acids, total polyunsaturated	0.069 g

Storage

They are highly perishable and de Almeida Sampaio *et al.* (2008) gave postharvest losses as up to 50% of the total production.

Diseases

Bautista Banos *et al.* (2000) reported that *Rhizopus stolonifer* was one of the main postharvest pathogens of red mombin fruit during handling and storage. They tested leaf extracts of various plants on the control of *R. stolonifer* both *in vitro* and *in vivo*. On inoculated fruit, leaf extracts of *Annona cherimola*, *Bromelia hemisphaerica* and *Carica papaya* inhibited *R. stolonifer* rot development on the yellow variety, whereas extracts of *Casimiroa edulis* reduced *R. stolonifer* rot on the red variety.

Star apple

Sapotaceae

Chrysophyllum cainito L. also called caimito and sweetsop. It is native to the West Indies and Central America. Fruit are produced on a tree that is up to 12 m in height and has attractive foliage that are dark

green and smooth on the upper surface and golden brown and silky on the under surface. The flowers are inconspicuous, small and purplish-white. The fruit are globose, smooth, green to purple and up to 10 cm in diameter. They contain several small brown seeds embedded in a sweet, white edible pulp that is eaten fresh. The skin contains unpleasant tasting latex and should be removed carefully (Kennard and Winters 1960, Purseglove 1975).

Harvesting

Kennard and Winters (1960) reported that the fruits do not fall naturally from the tree. Harvest maturity is critical since immature will be astringent and contain a sticky white latex and fully ripe fruit often split open, especially during the rainy season. However, fruits harvested at the half-ripe stage can be cured in a well-ventilated room for 2 days (Yahia 2002).

Pratt and Mendoza (1980) found that ethylene production at 20 °C was 10–100 nl kg⁻¹ h⁻¹ and that fruit did not respond much to treatment to exposure to ethylene. They found that it was a non-climacteric fruit and their respiration rate at 20 °C was 25–50 mg (13–25 µl) CO₂ kg⁻¹ h⁻¹. In contrast Kennard and Winters (1960) reported that the fruits should be harvested and ripened off the tree, which implies that they were climacteric. Yahia (2002) recommended optimum storage as 3–6 °C and 90% r.h. for about 3 weeks after curing.

Strawberry

Fragaria × ananassa Duch., Rosaceae. The edible part of the fruit is the fleshy receptacle, which is bright red, juicy and covered with small achenes. In non-climacteric such as strawberry there was little change in ethylene production during maturation (Manning 1993). However, he showed that auxin produced by the achenes could affect the colour (anthocyanin production) of the maturing fruit. Removal of the achenes from developing strawberry fruit resulted in quicker colouring of the area where they were removed.

They will freeze at about –1.4 to –1.1 °C (Wright 1942). Esters and terpenes were the most abundant aromatic fractions and enhancement of total volatile compounds after treatment with of methyl jasmonate

Table 186 The composition of strawberry fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	90.95 g	Thiamine	0.024 mg
Energy	32 kcal	Riboflavin	0.022 mg
Protein	0.67 g	Niacin	0.386 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.047 mg
Carbohydrate, by difference	7.68 g	Folate	24 µg DFE
Total dietary fibre	2.0 g	Vitamin B-12	0.00 µg
Total sugars	4.89 g	Vitamin A	1 µg RAE
Calcium	16 mg	Vitamin A	12 IU
Iron	0.41 mg	Vitamin E (α-tocopherol)	0.29 mg
Magnesium	13 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	24 mg	Vitamin D	0 IU
Potassium	153 mg	Vitamin K (phylloquinone)	2.2 µg
Sodium	1 mg	Fatty acids, total saturated	0.015 g
Zinc	0.14 mg	Fatty acids, total monounsaturated	0.043 g
Total ascorbic acid	58.8 mg	Fatty acids, total polyunsaturated	0.155 g

in combination with ethanol was observed (Blanch *et al.* 2012). Koyuncu and Dilmaçınal (2010) stored the cultivars Dorit and Selva in perforated (eight perforations, 10 mm diameter) plastic boxes at 0 °C and 90–95% r.h. for 10 days. They found that vitamin C content decreased in both cultivars. Among the acids citric acid was at the highest level and also decreased during storage in both cultivars as did malic acid, tartaric, oxalic and fumaric acids. The chemical content was given by USDA (2012) in Table 186.

Prestorage treatments

The cultivar Everest was treated with 1-MCP at various concentrations from 0 to 1000 nl L⁻¹ for 2 h at 20 °C and then stored for 3 days at 20 °C and 95–100% r.h. 1-MCP treatment lowered ethylene production and tended to maintain fruit firmness and colour, but disease development was quicker in fruit treated with 500 and 1000 nl L⁻¹. 1-MCP inhibited phenylalanine ammonia-lyase activity and reduced increases in anthocyanin and phenolic content (Jiang *et al.* 2001).

A coating comprising 1% high-molecular-weight chitosan and 3% lemon essential oil in a film-forming dispersion was applied to the cultivar Camarosa.

Chitosan coatings did not show a significant effect in terms of the acidity and TSS content of strawberries storage at 5 °C. However, strawberries coated with a combination of chitosan and lemon essential oil had a slower respiration rate and enhanced the chitosan antifungal activity both in *in vitro* tests and during cold storage in strawberries inoculated with a spore suspension of *Botrytis cinerea* (Perdones *et al.* 2012). Strawberries were treated with a solution of 1% chitosan, packaged in MA packages with either 80 or 5% O₂ and then stored at 4, 8, 12 and 15 °C. The coating inhibited the growth of microorganisms at all temperatures especially combined with high O₂ that also seemed to help in retaining colour (Tamer and Çopur 2010).

Vardar *et al.* (2012) applied chlorine dioxide, hydrogen peroxide, sodium hypochlorite, citric acid and ethanol to strawberry fruit using a fogger with an ultrasonic aerosol generator that can produce spheres at 1.2 µm in diameter. Fruit were treated at room temperature for 30 min while with the fogger operating and for an additional 30 min in the fog consisting of disinfectants. The fruit were stored at 1 °C for 5 days and an additional 2 days at 20 °C. The percentage of decay was reduced to 14.5% from 83.2% by the hydrogen peroxide treatment at 2000 µl L⁻¹ and to 32.5% by sodium hypochlorite at 2000 µl L⁻¹, and all chemicals significantly reduced the total number of microorganisms on the fruit surface and in the storage atmosphere. They concluded that the study showed that application of disinfectants by fogging was effective in reducing postharvest diseases of strawberry.

The overall results on strawberries from investigations by Nigro *et al.* (2000) indicated that treatment with low UV-C doses produced a reduction in postharvest decay related to induce resistance mechanisms. Pombo *et al.* (2011) reported that pre-storage treatment of fruit with UV-C resulted in lower losses caused by diseases and decay particularly disease caused by *Botrytis cinerea*. They concluded that the reduction in decay by UV-C treatment at harvest could be related to the increase in the transcription and activity of a set of enzymes and proteins involved in the defence against pathogens. Kim *et al.* (2010) found that postharvest treatments of either 50 mg L⁻¹ chlorine dioxide or 0.5% fumaric acid with 5 kJ m⁻² UV-C irradiation maintained the quality of the cultivar Maehyang better than those not treated. The combination reduced the initial populations of

total aerobic bacteria, yeast and fungi and better sensory scores.

Harvesting

Maturity is judged to be when they reach an even red colour over the whole surface. Being non-climacteric the fruit does not ripen after harvest. Strawberries are very susceptible to bruising and harvesting directly into retail punnets can reduce damage (Figure 121). However, mechanical harvesters have been developed (Figure 13), but the fruit are damaged and are used only for processing shortly after harvest. Harvesting aids are also commonly used for fruit for the fresh market. In Britain these are typically mounted on tractors that pass along rows of fruit with the harvesters laid, face downwards on padded beds with their hands free so they can harvest fruit directly into punnets as the while rig moves forward. The filled punnets are taken away and placed on trays that are then taken quickly to the packhouse for check weighing and despatch. This method of harvesting has been claimed to increase the amount harvested by 25% compared to hand harvesting not using the rig. Also those harvesters find the work less strenuous.

Precooling

Forced-air cooling with high humidity was the most acceptable, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling were less suitable (MAFF n.d.). Certainly hydrocooling would result in high levels of decay and vacuum cooling would be ineffective.

Coating

Han *et al.* (2004) coated strawberries with chitosan containing 5% Gluconal® CAL or chitosan containing 0.2% dl- α -tocopheryl acetate and stored them at 2 °C and 88% r.h. for 3 weeks. The coatings significantly decreased decay incidence and weight loss and delayed the change in colour and TA.

Postharvest physiology

They showed no response to exposure to 100 μL^{-1} of ethylene for 24 h at any temperature over the range 5–35 °C (Inaba *et al.* 1989). Their respiration rate was given in Table 187.



Figure 121 Harvesting strawberries in Paraguay directly into retail packs.

Table 187 Effects of temperature and reduced O_2 level on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{h}^{-1}$) of Cambridge Favourite strawberries (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	15	28	52	83	127
In 3% O_2	12		45		86

Storage

Most postharvest rotting is due to infections by *Botrytis cinerea*, which causes grey mould, and is usually the limiting factor in storage. At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for only about 1 day. Refrigerated storage recommendations include

- 0 °C and 85–90% r.h. for 1–5 days (Anonymous 1967);
- –0.6 to 0 °C and 85–90% r.h. for up to 10 days (Phillips and Armstrong 1967);
- 0 °C and 90–95% r.h. for 5 days (Mercantilia 1989);
- 6 °C for 3–4 days (Mercantilia 1989);

- 12 °C for 2–3 days (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 5–7 days (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 5–10 days (SeaLand 1991);
- 0 °C and 90–95% r.h. for 2–7 days (Snowdon 1990).

Controlled atmosphere storage

CO₂ levels of under 20% during storage at 0–2 °C can reduce *B. cinerea*. This was even effective at 5 or 15 °C (Harris and Harvey 1973). Woodward and Topping (1972) also showed that high levels of CO₂ in the storage atmosphere at 1.7 °C reduced rotting caused by infection with *B. cinerea*, but levels as high as 20% CO₂ were injurious to the fruit. High CO₂ can result in the production of off flavours (Couey and Wells 1970) and Hardenburg *et al.* (1990) also found that 30% CO₂ or less than 2% O₂ may cause off flavours to develop. In contrast firmness of the cultivar Pajaro was enhanced during storage in air at 0 °C by up to 3 days after CO₂ treatment at 40% at the beginning of storage (Harker *et al.* 2000). Low O₂ in the store atmosphere was shown to reduce their respiration rate particularly at the higher temperature (Table 187). Other storage recommendations include

- 0 °C and 90–95% r.h. with 15–20% CO₂ and 10% O₂ (SeaLand 1991);
- 3 °C with 20% CO₂ for 10 days, but after 15–20 days there was a distinct loss of flavour (Woodward and Topping 1972);
- 0–5 °C with 15–20% CO₂ and 10% O₂ or 5–10% O₂ (Kader 1985, 1989);
- 20 °C with either 20 or 25% CO₂ for 7 days resulted in the lowest decay, which was 14 and 11%, respectively, for the cultivar Tangi (Brackmann *et al.* 1999b).

Modified atmosphere packaging

Fruits of the cultivar Camarosa were packed in 500 g capacity polypropylene punnets and wrapped automatically with 25-µm-thick polypropylene film with micro-perforations. Fruits in these packages had lower losses during storage and the degree of 'fruit ripeness and nutritional value' were said to be better preserved. However, this modified atmosphere packaging seemed to reduce fruit colour, with

Table 188 The effects of thickness of polyethylene film on percentage decay of strawberries (source: adapted from Brackmann *et al.* 1999a)

	After 4 days at		After 7 days at	
	0 °C	20 °C	0 °C	20 °C
15 µm	2	18	–	79
30 µm	1	7	28	–
60.5 µm	0	8	27	–

lower anthocyanin levels, and led to off-flavour development (Sanz *et al.* 1999). Wrapping in PVC film reduced ascorbic acid loss by fivefold at 1 and 10 °C and twofold at 20 °C in the cultivars Chandler, Oso Grande and Sweet Charlie stored for 8 days. A combination of wrapping in PVC film and storage at 1 or 10 °C reduced ascorbic acid loss 7.5-fold compared to unwrapped fruits stored at 20 °C (Nunes *et al.* 1998). The cultivar Tangi packed in different polyethylene films had high decay levels but the thicker gauge plastic was better than the thinner gauge (Table 188). Almenar *et al.* (2007) tested storage of wild strawberries (*Fragaria vesca* L.) microperforated film packages and found that those with one and three perforations provided adequate CO₂ and O₂ equilibrium concentrations with good by sensory attributes during 6 days at 10 °C.

Hypobaric storage

It was reported by Haard and Salunkhe (1975) that the cultivars Tioga and Florida 90 could be stored for 21 days under reduced pressure compared to only 5–7 in cold storage. The effectiveness of short hypobaric treatments against postharvest rots was investigated by Romanazzi *et al.* (2001). On Pajaro, the greatest reductions of *B. cinerea* and *Rhizopus stolonifer* rot were observed on fruits treated for 4 h at 0.25 and 0.50 atm., respectively. An *et al.* (2009) studied hypobaric packaging in rigid small containers during storage at 3 °C with intermittent fresh air flushing and vacuum treatment to avoid creating an anoxic environment. Bacterial growth was slightly reduced in fruit in hypobaric packaging but there was an operational drawback with 25.3 kPa (0.25 atmosphere) in that fresh air flushing and repetitive vacuum application were required too frequently for the densely packed strawberry packages.

Table 189 The composition of cattley guava fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	80.66 g	Sodium	37 mg
Energy	69 kcal	Total ascorbic acid	37.0 mg
Protein	0.58 g	Thiamine	0.030 mg
Total lipid (fat)	0.60 g	Riboflavin	0.030 mg
Carbohydrate, by difference	17.36 g	Niacin	0.600 mg
Total dietary fibre	5.4 g	Vitamin B-12	0.00 µg
Calcium	21 mg	Vitamin A	5 µg RAE
Iron	0.22 mg	Vitamin A	90 IU
Magnesium	17 mg	Fatty acids, total saturated	0.172 g
Phosphorus	27 mg	Fatty acids, total monounsaturated	0.055 g
Potassium	292 mg	Fatty acids, total polyunsaturated	0.253 g

Strawberry guava

Myrtaceae

Psidium cattleianum Sabine synonymous with *P. littorale* Raddi. and *P. littorale* var. *lucidum* Degener, also called Cattley Guava. The edible portion is the round purplish red fruit up to 3 or 4 cm in diameter with white pulp. They have a sweet acid flavour somewhat resembling strawberries. *P. cattleianum* var. *lucidum* has yellow fruits. Strawberry Guava was said to have a promising future because of its pleasant delicate taste (Paniandy *et al.* 1999). It is a native of Brazil.

Charley (1969) gave the ascorbic acid content for red cattley as 29.1 mg 100 g⁻¹ and for yellow cattley as 39.2 mg 100 g⁻¹ grown in Florida and red or white cattley grown in Hawai'i as 25–50 mg 100 g⁻¹. The composition was given by USDA (2012) in Table 189.

Paniandy *et al.* (1999) suggested harvesting just before optimal maturity but this was not clearly defined. They also reported that in Reunion it has a very short shelf life in ambient conditions, which does not exceed 2 days, but fruits could be stored at 12–14 °C for up to 12 days.

Sudachi

Rutaceae

Citrus sudachi hort. ex Shirai. Sudachi is thought to be an *ichang papeda* – mandarin orange hybrid (*Citrus*

ichangensis × *C. reticulata* var. *austere*) that has been cultivated in parts of Japan for centuries. The plant has white flowers which bloom in May and June. The fruits form in bunches, or tight clusters, and are harvested in the fall. Though sudachi fruits will eventually develop a yellow-orange rind colour, they are normally harvested and used while still green.

Prestorage treatments

Since 1-MCP affects the response of fruit to ethylene and ethylene affects degreening it is surprising that 1-MCP should be useful in prolonging storage. However, sudachis were treated with 1-MCP at 0, 0.01, 0.1, 0.5 and 1.0 µl L⁻¹ for 6, 12 or 24 h at 20 °C and then stored at 20 °C by Isshiki *et al.* (2005). Treatment with 0.1 µl L⁻¹ 1-MCP was the most effective in delaying degreening and it did not induce peel browning and internal quality degradation. However, at 0.5 and 1.0 µl L⁻¹ 1-MCP had little effect on delaying degreening or inducing peel browning.

Storage

Noma *et al.* (2009) stored mature green sudachi fruit in a perforated polyethylene bag with a 0.3, 0.6, 1, 3 or 6 g ethanol pad as the ethanol vapour treatment and stored them at 20 °C. The fruit stored with 1 g ethanol pad had a slower decrease in chlorophyll and lower weight loss than control fruit, but there were no significant differences in the internal quality. Fruit with 3 or 6 g ethanol pads had higher levels of peel browning. Urushizaki (n.d.) described a device that reduced ethylene evolution, removed ethylene in the atmosphere and provided high CO₂ and low O₂, high moisture, reduced pressures and low temperatures. Sudachi fruit were successfully stored in the device with a combination of 5% CO₂, 17% O₂, 90–95% r.h., 660 torr and 3–5 °C for nearly 5 months.

Sugar cane

Gramineae

Saccharum officinarum L. also called Noble Cane. They produce thick stems and have been grown for chewing from ancient times in the Pacific Islands and Southeast Asia. This practice has spread throughout the tropics wherever sugar cane is grown and an

export trade had developed to European and North American countries. There are various species of *Saccharum* grown commercially for sugar extraction but the noble cane is preferred for chewing since they are relatively soft and have both a high juice and a sugar content (Purseglove 1972).

Harvesting

This should be when the sugar content has reached its peak and is usually 14–18 months after planting and 12 months for ratoons. Retarding the growth rate by withholding irrigation and fertilisers are used to hasten maturation (Purseglove 1972).

Peeling and Cutting

The stems are normally cut into short lengths before being sold and may often be peeled. Peeling and cutting stimulated the increase of respiration rate of sugarcane by more than eight times. The shorter the sugarcane section, the more the respiration rate increased (Mao and Liu 2000).

Storage

During storage of the cultivar Badila in China, activities of sucrose invertases and polyphenol oxidase increased gradually, titratable acid, alcohol and reducing sugar contents increased, while sucrose and soluble sugar contents decreased. Peeled sugarcane, combined with vacuum packaging, could be stored for 20 days at 0 °C (Mao and Liu 2000). Verma *et al.* (2012) also found that extractable sucrose percentage in juice declined significantly with increasing storage periods from 1 to 5 days and increasing temperature over the range of 17–41 °C. Activities of invertase enzymes were significantly negatively correlated with the sucrose percent and showed a sharp increase during storage and there was a rapid increase in acidity that was also higher at higher temperatures. There were significant differences in the reduction of sucrose percent in different cultivars during storage. Frateschi *et al.* (2013) studied CA storage and found that storage in atmospheres containing 1 or 5% O₂ reduced their respiration rate, POD activity and reducing sugar content compared to 10, 15 or 21% O₂ but did not affect their PPO activity or colour.

Sweet calabash

Passifloraceae

Passiflora maliformis L. Other common names include conch apple, wild purple passionfruit and sweet cup. It is native and common in the wild in Cuba, Puerto Rico, the Dominican Republic, Jamaica, and from Saba to Barbados and Trinidad; also Venezuela, Colombia and northern Ecuador. It is cultivated in Jamaica, Brazil and Ecuador for its fruits. It grows and fruits at cool altitudes up to 1700 m in South America and Jamaica between 152 and 366 m (Morton 1987). It is usually eaten fresh or used to flavour drinks.

It is a fast growing woody but slender vine, climbing to 10 m or more by means of tendrils in the leaf axils. The peduncle forms a background for the opened flower that is fragrant, 5–6 cm wide, with keeled, green, maroon-dotted sepals and five small petals, greenish-white, dotted with red or purple. The corona is three-ranked and variegated white, purple and blue. The fruit is oblate to nearly round-oval. It is 4.5–5 cm long and 3.5–4 cm wide. The peel is purple, yellow or green and is thin and particularly hard, and tougher than most passion fruits. The pulp is greyish or pale orange-yellow, juicy, sweet or sub-acid, aromatically scented and flavoured, containing many black, flat, ovate, pitted seeds. The fruit is difficult to open and in Jamaica it is scooped from the shell or used for making cold drinks (Morton 1987).

Sweet granadilla

Passifloraceae

Passiflora ligularis Juss., also called granadillo. It is common from central Mexico through Central America and western South America, through western Bolivia to south-central Peru. Throughout this region, it is popular and abundant in the markets. It has been grown in Hawai'i since late in the 19th century. It may be grown to some extent in New Guinea and it is cultivated and naturalized in Jamaica and Haiti (Morton 1987).

The vine is vigorous climbing by tendrils. The flowers have a sweet, musky in odour, and are up to 10 cm wide, with pinkish white petals. The edible portion is the orange-brown ovoid fruit that are up to 7.5–10 cm in diameter. They have a hard skin

Table 190 The composition of fresh weight pulp and seeds combined for sweet granadilla from Ecuador, El Salvador, Costa Rica and Guatemala for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	69.9–79.1 g	Phosphorus	44.0–78.0 mg
Protein	0.340–474 g	Iron	0.58–1.56 mg
Fat	1.50–3.18 g	Carotene	0.00–0.035 mg
Crude Fibre	3.2–5.6 g	Thiamine	0.00–0.002 mg
Ash	0.87–1.36 g	Riboflavin	0.063–0.125 mg
Calcium	5.6–13.7 mg	Niacin	1.42–1.813 mg
		Ascorbic acid	10.8–28.1 mg

that is green with purple blush on sunny side and minutely dotted when unripe, orange-yellow with white specks when ripe. Inside there is a whitish aromatic, mucilaginous, very juicy pulp containing many flat black seeds (Morton 1987). The chemical content was given by Morton (1987) in Table 190.

They are harvested by hand from the vines when the colour begins to change from green to orange. Chilling injury was observed in fruits stored at 5 °C after 35 days but not after 28 days (Parodi and Campbell 1995). However, storage at 0 or 2.2 °C for 2–3 months resulted in no deterioration in Hawai'i (Wardlaw 1937). Fruits harvested at the green mature or slightly mature stage were stored at 5 °C for 28 or 35 days. Juice pH was higher in slightly mature than green mature fruits. TSS were similar among treatments, but green mature fruits stored for 28 days had less colour development than those stored for 35 days (Parodi and Campbell 1995). The fruit, despite its hard shell, has poor keeping quality, deteriorating soon after the harvest (Morton 1987).

Sweet passionfruit

Passifloraceae

Passiflora alata Dryand. In Brazil they differentiate between two similar looking fruit: sweet passion fruits (maracujas doce, *P. alata*) and acid passion fruits (maracujas acido, *P. edulis*). Their flowers open early in the morning and last about 12 h and emit a sweet aroma.

The fruit are normally harvested after they turn from green to yellow when they are considered mature (Veras *et al.* 2000). They found that they could be harvested up to 4 days before fruit abscission without affecting quality. da Silva *et al.* (1999b) found

that pre-treatment with StaFresh wax (1:2) helped to maintain their quality. Treatment with 1% calcium chloride at –25 kPa vacuum for 1 min and +25 kPa pressure for 1 min gave the lowest percentages of weight loss and delayed changes in peel colour during storage at 9 °C and 85–90% r.h. for 30 days (da Silva and Vieites 2000). During storage at 9 °C for 28 days fruits that had been treated with benzyladenine maintained ascorbic acid and soluble solids levels better than untreated (da Silva *et al.* 1999a). da Silva *et al.* (1999b) successfully stored the cultivar Dryander for 30 days at 9 °C and 85–90% r.h.

Sweetsop

Annonaceae

Annona squamosa L. Other common names include sugar apple and custard apple. It is a native of Central America and the Caribbean region, or possibly more precisely Southeastern Mexico, in dry areas and up to 1000 m in altitude.

It is a small tree which grows wild in many places in the north of South America, Central America and the Caribbean region. It is an aggregate fruit, which is made up of loosely coherent small berries or carpals. They are subglobose or ovoid in shape, with a yellowish green skin covered with a bluish white bloom (Figure 122). The flesh is white and custard-like with a sweet flavour and a granular texture containing numerous small brown shiny seeds. When ripe the carpels pull away easily and they may split on the tree if left to mature fully. The pulp may be eaten raw and tastes aromatic and sweet, with a custard-like flavour. The name custard apple is used for *A. squamosa* in some Asian countries, but it more commonly refers to *A. reticulata*. The chemical content was given by USDA (2012) in Table 191.

Harvesting

Harvest maturity can be assessed on colour change of the skin. In practice this is usually combined with feeling the fruit to judge texture, smelling the odour and looking at the bloom on the surface. In China colour change has been developed to measure percentage maturity (Chen 1998). Fruits harvested at 90% maturity exhibited the best quality compared to those harvested at an earlier stage. However, they had



Figure 122 Sweetsop (*Annona squamosa*) growing in Malaysia.

the shortest storage life of 2 days compared with 4 and 6 days for 80 and 70% mature fruits, respectively, at room temperature of 25–33 °C. There was no significant difference in quality between fruits picked at 90% maturity and those picked at 80% maturity. Peduncle browning was the lowest in fruits picked at 80% maturity.

1-MCP

Hofman *et al.* (2001) found that exposure of the cultivar Africa Pride to 1-MCP at 25 µl L⁻¹ for 14 h at 20 °C increased the number of days to ripening by 3.4 days (58%) compared with non-treated fruit. 1-MCP treatment was associated with slightly higher severity of external blemishes and slightly higher rot severity compared to non-treated fruit. Since the 1-MCP treatment countered the effects of exogenous ethylene they concluded that it has the potential to reduce the risk of premature ripening because of accidental exposure to ethylene.

Postharvest physiology

During storage at 25 or 20 °C fruit had a clear climacteric peak, whereas those stored at 15 and 10 °C did

Table 191 The composition of sweetsop fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

	Custard Apple, Bullock's Heart	Sugar Apple, Sweetsop
Water (g)	71.50	73.23
Energy (kcal)	101	94
Protein (g)	1.70	2.06
Total lipid (fat) (g)	0.60	0.29
Carbohydrate, by difference (g)	25.20	23.64
Total dietary fibre (g)	2.4	4.4
Calcium (mg)	30	24
Iron (mg)	0.71	0.60
Magnesium (mg)	18	21
Phosphorus (mg)	21	32
Potassium (mg)	382	247
Sodium (mg)	4	9
Zinc (mg)	—	0.10
Total ascorbic acid (mg)	19.2	36.3
Thiamine (mg)	0.080	0.110
Riboflavin (mg)	0.100	0.113
Niacin (mg)	0.500	0.883
Vitamin B-6 (mg)	0.221	0.200
Folate (µg DFE)	—	14
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg RAE)	2	0
Vitamin A (IU)	33	6
Fatty acids, total saturated (g)	0.231	0.048
Fatty acids, total monounsaturated (g)	—	0.114
Fatty acids, total polyunsaturated (g)	—	0.040

not show any distinct rise in respiration rate. Ethylene peak was 2.40 µl kg⁻¹ h⁻¹ and it coincided with the respiratory climacteric at 25 °C, which also corresponded with the peaks in TSS, sugars, ascorbic acid and acidity (Prasanna *et al.* 2000). Chen and Zhang (2000) found that the climacteric peak was after 2–3 days during storage at 27–33 °C and 85–90% r.h. and coincided with fruit softening and splitting. TSS, total sugar and reducing sugar contents increased during storage, whereas titratable acid and ascorbic acid contents decreased (Bhadra and Sen 1999).

Storage

Fruit stored at 11 °C were found to turn brown or black (Smith 1936). Refrigerated storage recommendations include

- 7.2 °C and 85–90% r.h. for 4 weeks (turning) (Pantastico 1975);
- 1.1 °C and 85–90% r.h. for 2 weeks (ripe) (Pantastico 1975);
- 10–15 °C and 90% r.h. for 1–2 weeks (Snowdon 1990);
- 7.2 °C and 85–90% r.h. for 28 days (SeaLand 1991);
- 10 °C and 85–90% r.h. (Bhadra and Sen 1999);
- 15–20 °C for 4–6 days (Prasanna *et al.* 2000).

Controlled atmosphere storage

Controlled atmosphere storage of the cultivar Tsulin at 20 °C with 5% CO₂ and 5% O₂ resulted in reduced ethylene production levels and delayed ripening (Tsai and Wu 1989).

Modified atmosphere packaging

Placing fruits in sealed polyethylene bags with potassium permanganate ethylene absorbent reduced fruit spoilage retained their natural colour and increased their storage life. Storage in perforated polyethylene also retarded ripening (Bhadra and Sen 1999).

Ripening

The major changes during ripening were a continuous decrease in fruit firmness and starch content and a continuous increase in TSS and sugars (Prasanna *et al.* 2000). Fruits were ripe after 4 days at 25 °C, 6 days at 20 °C and 9 days at 15 °C (Prasanna *et al.* 2000). They also found that the colour of the pulp, texture, taste and flavour were superior when ripened at 25 and 20 °C, followed by fruits stored at 15 °C, but fruits ripened at 10 °C became hard with surface blackening, 'messy' pulp and less sweetness. Dipping in Ethrel at 1.5 or 2.5 ml L⁻¹ enhanced fruit ripening at 28–32 °C and 70–75% r.h. (Bhadra and Sen 1999).

Tangerines

Rutaceae

Citrus reticulata Blanco, *C. unshiu* (Swingle) Marcow. The fruit is a berry or hesperidium, which is non-climacteric. The term *tangerine* refers to most mandarin types in most of the United States and

Table 192 The composition of tangerine fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	85.17 g	Thiamine	0.058 mg
Energy	53 kcal	Riboflavin	0.036 mg
Protein	0.81 g	Niacin	0.376 mg
Total lipid (fat)	0.31 g	Vitamin B-6	0.078 mg
Carbohydrate, by difference	13.34 g	Folate	16 µg DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Total sugars	10.58 g	Vitamin A	34 µg RAE
Calcium	37 mg	Vitamin A	681 IU
Iron	0.15 mg	Vitamin E (α-tocopherol)	0.20 mg
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	20 mg	Vitamin D	0 IU
Potassium	166 mg	Vitamin K (phyloquinone)	0.0 µg
Sodium	2 mg	Fatty acids, total saturated	0.039 g
Zinc	0.07 mg	Fatty acids, total monounsaturated	0.060 g
Total ascorbic acid	26.7 mg	Fatty acids, total polyunsaturated	0.065 g

to the more deeply pigmented mandarins in Australia and China (Davies and Albrigo 1994). They will freeze at about -1.8 to -1.4 °C (Wright 1942). The chemical content was given by USDA (2012) in Table 192.

Degreening

Optimum temperatures range between 25 and 29 °C and humidity as high as possible, generally between 90 and 95% r.h. with ethylene at between 1 and 10 µl L⁻¹ for 24–72 h.

Storage

The only recommendation that could be found was 7.2 °C and 85–90% r.h. for 14–28 days was recommended by SeaLand (1991).

Diseases

Boonkorn *et al.* (2012) found that exposing artificially inoculated tangerine fruit of the cultivar Sai Nam Pung to ozone for 4 and 6 h delayed disease incidence and reduced severity of green mould (*Penicillium digitatum*).



Figure 123 Tayberries growing in Britain. See colour plate section.

Tayberries

Rosaceae

Rubus sp. It is a hybrid between the tetraploid raspberry (*R. idaeus*) and the American blackberry (*R. ulmifolius*) and was bred in Scotland hence its common name. Related types are sunberries, tummelberries and wineberries. The fruit is a collection of drupes that are bright red in colour when mature and elongated in shape (Figure 123). They have an aromatic flavour and a rich but slightly acid flavour and are borne on long spiny canes. It is classified as a non-climacteric fruit. No specific information on storage could be found but they can probably stored in similar conditions to raspberries of 0 °C and 85–90% r.h. for about 2–3 days.

Watermelon

Cucurbitaceae

Citrullus lanatus (Thumb.) Mansf. It is native to tropical and subtropical Africa where it forms a small and somewhat bitter fruit which is a fleshy berry. It was grown in the Mediterranean area and India from ancient times but was taken to China only in the 10th and 11th centuries CE (Purseglove 1975).

Modern cultivars of fruit are large and oblong to globular in shape. The skin is usually mottled green or striped, but dark green and brown fruit are grown. The flesh is juicy with many black or brown seeds and usually dark red, but can be pink, white or yellow. The flesh will freeze at about –1.7 to –1.4 °C (Wright

Table 193 The composition of watermelon fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	91.45 g	Thiamine	0.033 mg
Energy	30 kcal	Riboflavin	0.021 mg
Protein	0.61 g	Niacin	0.178 mg
Total lipid (fat)	0.15 g	Vitamin B-6	0.045 mg
Carbohydrate, by difference	7.55 g	Folate	3 µg DFE
Total dietary fibre	0.4 g	Vitamin B-12	0.00 µg
Total sugars	6.20 g	Vitamin A	28 µg RAE
Calcium	7 mg	Vitamin A	569 IU
Iron	0.24 mg	Vitamin E (α-tocopherol)	0.05 mg
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	11 mg	Vitamin D	0 IU
Potassium	112 mg	Vitamin K (phylloquinone)	0.1 µg
Sodium	1 mg	Fatty acids, total saturated	0.016 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.037 g
Total ascorbic acid	8.1 mg	Fatty acids, total polyunsaturated	0.050 g

1942). The chemical content was given by USDA (2012) in Table 193.

Harvesting

If fruit are too immature at harvest they will not ripen (Wardlaw 1937). The tendril accompanying the fruit becomes shrivelled when the fruit is mature and can be used to judge harvest maturity. Also the portion resting on the ground changes colour from white to creamy yellow and it produces a dull hollow sound when tapped. The measurement of electrical properties can be used to determine fruit ripeness. In watermelons specific electrical resistance appeared to decrease with increasing sugar content (Nagai 1975). In Japan the measurement of acoustic impulse responses has been developed and a machine was installed in commercial packing facilities (Kouno *et al.* 1993a). It is being used for watermelons to detect both the ripeness and any hollowness in the fruit. Nine machines were installed and they were found to be as accurate in grading melons as skilled inspectors using 'the traditional slapping method'.

Postharvest physiology

The fruit is classified as climacteric. Respiration rate was given as 4 at 0 °C, 8 at 10 °C and 21 mg kg⁻¹ h⁻¹ at 20 °C and ethylene production of about 1 µl kg⁻¹ h⁻¹ at 20 °C (Gross *et al.* 2002). Flesh red colour was intensified during storage at 21.1 °C (Lutz and Hardenburg 1968). The application of potassium to watermelons during growth was shown to decrease the respiration rate of the fruit after harvest (Cirulli and Ciccarese 1981).

Storage

In Jamaica it is claimed that the cultivar Charleston Grey can occasionally be kept at room temperature for several months without decay, while at other times it spoils within a few days of harvest. In the Kordofan area of the Sudan a round brown skin type can be kept in good condition for a year in very hot arid desert conditions and is used as a source of drinking water. At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that watermelons could be kept for only 8–12 days. Chilling injury can occur in storage below 7 °C and loss of skin colour may occur during storage below 10 °C (Tindall 1983). Fruits held for 1 week at 0 °C showed surface pitting and had objectionable flavours (Lutz and Hardenburg 1968, Phillips and Armstrong 1967) and those stored at 1.7 °C for 2 months appeared to be sound externally but were inedible when cut open (Wardlaw 1937). Refrigerated storage recommendations include

- 7.2–15.6 °C and 80–90% r.h. for 2 weeks with 2.2–4.5 °C and 85–90% r.h. for 2–3 weeks (Anonymous 1967);
- 2.2–4.4 °C and 85–90% r.h. for 2–3 weeks (Phillips and Armstrong 1967);
- 4.4–10 °C and 80–85% r.h. for 2–3 weeks (Lutz and Hardenburg 1968);
- 2.8–3.9 for 2–3 months (Russia) (Lutz and Hardenburg 1968);
- 8–15 °C and 80–85% r.h. since chilling injury can occur in storage below 7 °C and loss of skin colour may occur during storage below 10 °C (Tindall 1983);
- 5–6 °C and 80–85% r.h. for 16–20 days (Mercantilia 1989);
- 10–15 °C and 90% r.h. for 2–3 weeks (Snowdon 1990);

- 10–12 °C and 90% r.h. for 2–3 weeks (Snowdon 1990);
- 10 °C and 85–90% r.h. for 14–21 days (SeaLand 1991).

Controlled atmosphere storage had only a slight to no effect (SeaLand 1991).

Diseases and disorders

A range of fungi can attack the fruit postharvest, but careful handling and applying copper sulphate to the end of the fruit stalk directly after harvest gave good control (Wardlaw 1937). Snowdon (1990) reviewed other diseases and their control.

White heart has been associated with adverse weather conditions during fruit growth (Wardlaw 1937). Imbalance of fertilizers can result in the physiological disorder of watermelon called blossom end rot (Cirulli and Ciccarese 1981).

Losses

In a study in Mexico fruits were transported loose in lorries and on arrival at the market were unloaded by hand and stacked in piles. Most defects were superficial resulting from mechanical injuries during production and postharvest handling. Severe mechanical damage, aggravated by over-maturity of some fruits, accounted for 5.7% loss during transport and an estimated 2% during subsequent marketing (Noon 1979).

Wax apple

Myrtaceae

Syzygium samarangense (Blume) Merrill & L. M. Perry. It originated in Southeast Asia. The fruit is broad, bell shaped, sometimes oval, 5–6 cm long and 4–5 cm in diameter, with one to four seeds. The skin can be green to light red to dark red and has a wax-like high gloss sheen. The flesh is white, juicy and low acid (Nakasone and Paull 1998).

It is a non-climacteric fruit (Akamine and Goo 1979b) and produced very low amounts of ethylene. Respiration rate was 4–5 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 8–11 mg CO₂ kg⁻¹ h⁻¹ at 20 °C and declined after harvest (Liao *et al.* 1983).

A moisture loss of 2% resulted in fruit becoming slightly shrivelled and 6% resulted in fruit becoming shrunken and losing their turgidity. They showed pitting and skin scald after storage of 4 days at 2 °C while slight injury occurred after 4 days at 10 °C. Storage at 2–10 °C resulted in chilling injury and 12–14 °C and 90–95% r.h. was recommended for 10–14 days (Horng and Peng 1983). They also found that storage in sealed PE film bags reduced chilling injury and decay.

West Indian gooseberry

Euphorbiaceae, Phyllanthaceae

Phyllanthus acidus (L.) Skeels, *P. distichus* Muell. Arg., *Cicca acida* Merr., *C. disticha* L. Other common names include grosella and otaheite gooseberry. Its origin is possibly India and Madagascar and it was taken to the Philippines in prehistoric times. It was carried across the Indian Ocean to Réunion and Mauritius and across the Pacific as far as Hawai'i. It was taken to Jamaica in 1793, when William Bligh carried plant from Timor. From Jamaica it was taken to South America.

It is a small tree up to about 9 or 10 m high and produces clusters of tiny red flowers and pale green or yellowish fruit with six ribs, each containing a flat brown seed. Fruits are up to 3 cm in diameter and they resemble the gooseberry (*Ribes grossularia*) in flavour but are even more acidic. They are waxy, crisp, juicy and light yellow in colour when fully ripe. They contain a hard, ribbed stone. When stewed with sugar they turn bright red. They were reported to have an ascorbic acid content of only 7.54 mg 100 g⁻¹ of pulp (Kennard and Winters 1960). Harvest maturity is based on skin colour that turns pale green or yellow. The chemical content of the fruit was given by Morton (1987) in Table 194.

White sapote

Rutaceae

Casimiroa edulis Llave & Lex. Other common names include cochitzapotl, zapote blanco and zapote. It is also called matasano in Spanish meaning 'killing healthy person' because of the presence of the glucoside casimiroside, mainly in seeds and also in the bark

Table 194 The composition of the edible portion of West Indian gooseberry fruit from El Salvador for 100 g⁻¹ fresh weight (source: Morton 1987)

Moisture	91.9 g
Protein	0.155 g
Fat	0.52 g
Fibre	0.8 g
Ash	0.51 g
Calcium	5.4 mg
Phosphorus	17.9 mg
Iron	3.25 mg
Carotene	0.019 mg
Thiamine	0.025 mg
Riboflavin	0.013 mg
Niacin	0.292 mg
Ascorbic acid	4.6 mg

and leaves (Yahia 2002). It originated in Mexico and there is evidence of its cultivation there in the period 5000–3000 BCE (Purseglove 1975).

The fruit are borne on tropical evergreen trees that can be up to 16 m high. The fruit is an ovoid drupe, up to 10 cm in diameter, with thin inedible green peel turning yellow when ripe. The pulp can be creamy-white in green skin varieties or a beige-yellow in yellow skin varieties and has a smooth texture, which can range in flavour and contains up to five large seeds. Overripe fruit are commonly pungent with an unpleasant flavour. Its respiratory pattern led to it being classified as an indeterminate fruit by Biale and Barcus (1970). Murillo *et al.* (2007) found that the seeds contain many pharmacologically active compounds including zapotin that has been shown to have potential anti-carcinogenic effects against isolated colon cancer cells.

Harvest maturity is when the skin colour changes from green to yellowish, but the fruit is still firm. Yahia (2002) reported that they ripen 6–9 months after blooming and taste best when allowed to ripen on the tree but should be picked before ripening and handled very carefully because they are easily bruised, which causes the skin to turn black and the flesh beneath it becomes bitter.

Mature fruit will soften at tropical ambient conditions in 2 or 3 days. Refrigerated storage recommendation was 19.4 °C and 85–90% r.h. for 2–3 weeks (SeaLand 1991) and 19–21 °C and 85–90% r.h. for 2–3 weeks (Yahia 2002).

Wild cucumber

Cucurbitaceae

Cyclanthera pedata var. *edulis* Schrad., also called pepino. It is a vigorous annual vine, native of Mexico, whose fruits (fleshy berry-like structures) are called a pepo. Fruit are yellowish or green slightly spiny, ovoid in shape, about 5 cm long and hollow with many seeds. They have a strong smell. The only storage recommendation that could be found was 7–10 °C and 85–90% r.h. for 1–2 weeks (Hardenburg *et al.* 1990).

Worcester berries

Saxifragaceae, Grossulariaceae

Ribes divaricatum although some authorities reported that it was a hybrid between a gooseberry (probably *R. hirtellum* Michx.) and a blackcurrant (*R. nigrum* L.). Worcester berry originated in the west coastal areas of North America and was introduced into Europe around 1826. It is sometimes called American gooseberry and the name Worcester berry was apparently given to it by a nurseryman in Worcester (a small town in Massachusetts in the United States about 60 km west of Boston) who considered it a gooseberry/blackcurrant hybrid. It is sometimes confused with the Jostaberry, which is thornless.

It is a small, vigorous, very thorny, bush with vicious spines. It is resistant to American gooseberry mildew, and big bud mite but is susceptible to sawfly whose larvae may completely eat all the leaves. The fruits change colour from green, through red, to dark red and then almost black as they mature and ripen. The fruit is duller than that of the blackcurrant and has a particularly long remnant of the flower petals still attached even when fully mature. Fruits look like a small smooth skinned gooseberry when green and are the size of a large blackcurrant, but the flavour is more mellow.

The fruit is ripe when it turns black. Red berries are relatively easy to harvest but when they turn black the skin tends to tear rather than snap off from the stalk. They can be harvested while red and still tart or allowed to ripen to a dull black colour. The fruit is difficult to pick because of the vicious spines. The easiest way to pick the fruit is to lift the tip of

Table 195 The composition of yard-long beans for 100 g⁻¹ fresh weight (source: adapted from USDA 2012)

Water	8.43 g	Thiamine	0.887 mg
Energy	347 kcal	Riboflavin	0.235 mg
Protein	24.33 g	Niacin	2.158 mg
Total lipid (fat)	1.31 g	Vitamin B-6	0.371 mg
Carbohydrate, by difference	61.91 g	Folate	658 µg DFE
Total dietary fibre	11.0 g	Vitamin B-12	0.00 µg
Calcium	138 mg	Vitamin A	3 µg RAE
Iron	8.61 mg	Vitamin A	52 IU
Magnesium	338 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	559 mg	Vitamin D	0 IU
Potassium	1157 mg	Fatty acids, total saturated	0.339 g
Sodium	17 mg	Fatty acids, total monounsaturated	0.114 g
Zinc	3.50 mg	Fatty acids, total polyunsaturated	0.565 g
Total ascorbic acid	1.6 mg		

the branch up high, allowing the Worcester berries to hang down, when they can be easily seen and picked off.

Yard-long bean

Fabaceae, Leguminosae

Vigna unguiculata subsp. *sesquipedalis* (L.) Verde., synonymous with *V. sesquipedalis* (L.) Fruhw. Other common names include asparagus bean and pea bean. It is considered native to Southern Asia where it is grown especially Southeast Asia, Indonesia and the Philippines, also in the Caribbean region (Kay 1979). It is an annual vigorous climber up to 2.4 m high. The pods vary in length and are fleshy and pendant containing up to 20 seeds. They are eaten raw in salads when immature and boiled as vegetables when more mature (Kay 1979). The chemical content was given by USDA (2012) in Table 195.

Harvesting

Harvest maturity is when they are half to two-thirds mature otherwise they become tough and fibrous and this maturity usually occurs 50–65 days after sowing. They are harvested by hand every 2–4 days (Kay 1979).

Postharvest physiology

Respiration rates for immature pods were 46 at 10 °C and 110 $\mu\text{l CO}_2 \text{ g}^{-1} \text{ h}^{-1}$ at 20 °C and they produced very little ethylene, but exposure to 10 ppm caused accelerated colour and ripening-related changes (Zong *et al.* 1992). Zong *et al.* (1993) gave the following respiration rates 20 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 0 °C, 23 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 5 °C, 32 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 7.5 °C, 46 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 10 °C, 74 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 12.5 °C, 101 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 15 °C and 110 ml $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 20 °C.

Storage

Zong *et al.* (1992) stored immature pods at 0, 5, 7.5, 10, 12.5, 15 and 20 °C and 90–95% r.h. followed by 2–3 days at 20 °C. They found that chilling injury occurred after storage for 2 weeks below 10 °C, with symptoms included pitting, russeting, black and brown surface discolorations and a high incidence of decay. Seed development and colour

changes continued during storage at temperatures greater than 12.5 °C.

Zapotes chupa chupa

Malvaceae, Steruliaceae, Bombacaceae

Matisia cordata H.B.K; *Quararibea cordata* (Humb. et Bompl.) Garc. et Hern., *Q. cordata* Vischer, also called sapote Andino. It is a semi-deciduous tree up to 45 m in height, which is native to Amazon rainforest vegetation in Brazil, Colombia, Ecuador and Peru. It bears orange-yellow fruit, which are soft, juicy, sweet and fibrous and contain two to five seeds and are usually eaten fresh. They are oval in shape with an apical projection and a persistent calyx. The skin is grey brown in colour with a felt-like texture. The only reference to postharvest behaviour was a recommended storage condition of 6–9 °C and 90–95% r.h. (Amezquita 1973).

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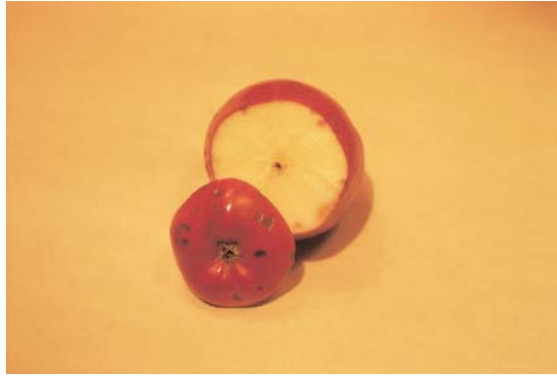


Figure 1 Bitter pit on a Red Delicious apple in Turkey.



Figure 3 Colour chart to facilitate colour grading of tomatoes. (Source: OECD 2003. Reproduced with permission.)



Figure 20 Carton used for parsnip showing the emphasis on hydrocooling.



Figure 23 Hydrocooling litchi in Thailand in preparation to loading for reefer container transport to Singapore. The fruit are in plastic trays and the bags contain ice to place in the hydrocooling water.



Figure 31 Wooden boxes used for transporting fruit and vegetables in Eritrea.



Figure 53 Portable Tubamet Swingcat ethylene scrubber in use in a wholesale packhouse in United Kingdom.



Figure 57 A retail fruit and vegetable market in Bedford, UK.



(a)



(b)



(c)

Figure 67 (a) Three-tier pressurised banana ripening system. (b) Two-tier 26-pallet banana ripening room. (c) Random access fruit ripening room typically used for the ripening of avocados and mangoes. (Source: MTX Contracts Ltd.)



Figure 69 Harvest maturity of babaco is when the fruit have begun to turn yellow.

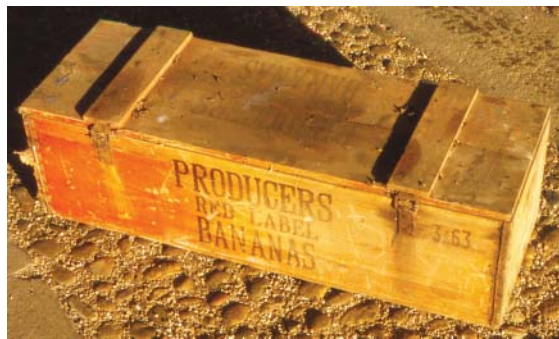


Figure 70 Wooded returnable box used for distribution of a single bunch of bananas from the ripening room to the retail market in United Kingdom in the 1950s.



Figure 73 Banana transport in Eritrea in 2013.



Figure 76 Plastic covering for control of crown rot disease in organic bananas in 2013.



Figure 77 Under peel discoloration in a banana. (Photo: A.J. Hilton. Reproduced with permission of Cranfield University.)



Figure 78 Matoke bananas being transported to market in Uganda in July2009. Note that they are packed in split banana pseudostem to protect them during transport.



Figure 82 Banana passionfruit growing close to Bogota in Colombia.



Figure 83 Baobab tree showing new leaves and young developing fruit from the present season with mature fruit from the previous season that had not been harvested. Photograph taken just after the onset of the rainy season in Keren in Eritrea in May 2013.



Figure 84 Blackberry showing developing fruit and fruit ready for harvesting.



Figure 85 Bilberry growing wild in West Yorkshire in the United Kingdom.



Figure 86 Cashew fruit showing the progression of their development with the nut (the true fruit) developing earlier than the fruit stalk (the pedicel).



Figure 87 Minneola is a hybrid between a Duncan grapefruit and a Dancy tangerine.

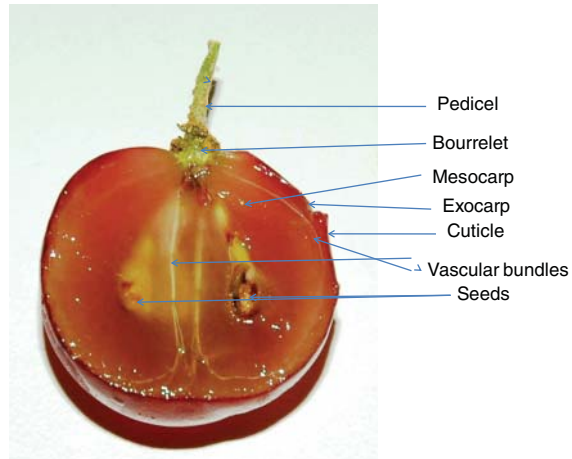


Figure 90 Section through a grape fruit. (Photo: Caitlin Thompson.)



Figure 91 Harvesting grapes at Hagaz in Eritrea. (Photo: D. Okubamicael Haile.)



Figure 92 Grape harvesting in Hagaz in Eritrea loading plastic boxes containing the fruit onto a trailer for transport to the packhouse. (Photo: D. Okubamicael Haile.)



Figure 93 Guavas grown in Thailand and packed ready for the market. There are some large cultivars in Thailand that are crisp and sweet when still unripe and can be eaten like desert apples.



Figure 95 Fresh Jamaican sorrel (*Hibiscus sabdariffa*) from the West Indies on the UK market.



Figure 97 Kumquats ready for harvesting in Mexico.



Figure 103 Chinese okra (*Luffa acutangula*) on sale in Californian market.



Figure 104 Rose apples on sale in Thailand.



Figure 107 Bag and cutter used for attaching to a long pole for harvesting mangoes in Colombia.



Figure 108 Circular mango weight grader in use in a packhouse in Brazil.

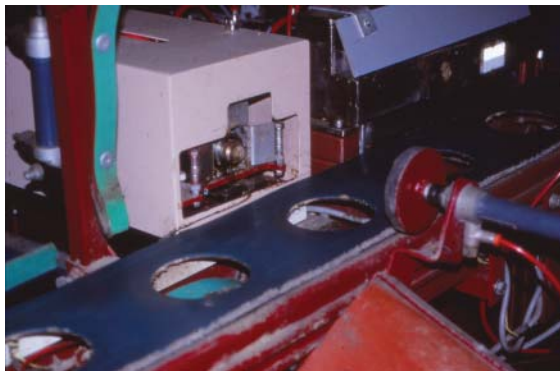


Figure 109 Melon packhouse in Spain showing the equipment for automatic measurement of total soluble solids. (Photo: Fernando Cosman.)



Figure 111 Transport and marketing of pineapples in Uganda in July 2009.



Figure 112 Monarch plums, ready for harvesting, growing in the United Kingdom.



Figure 113 Prickly pear fruit imported into Britain being offered for sale in a wholesale market.



Figure 117 White currants ready for harvesting growing in Britain.



Figure 118 Salak fruit in a market in Thailand.



Figure 123 Tayberries growing in Britain.

Fruit and Vegetables

To

*Elara, Maya, Ciaran, Caitlin and Cameron
to whom I owe much more than they will ever know*

Fruit and Vegetables

Harvesting, Handling and Storage

Third Edition

Volume 2

Vegetables, Mushrooms, Herbs

A.K. Thompson

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1

Introduction

The Oxford Dictionary's definition of vegetables is 'any of various plants, especially herbaceous plants, used wholly or partly for food'. But this clearly leaves some questions. If we define vegetables botanically then tomatoes, aubergines, capsicums, ackees and many others would be fruit. So perhaps a better definition is in terms of their use. Another group which are often defined separately by the wholesale and retail fresh produce sectors are salad crops which may be separated from other vegetables as those that are usually eaten fresh without cooking. However, many eastern Asian dishes use cooked lettuce, and raw carrots and cabbage are used in many fresh salads all over the world. I used to work for a UK Government research department that was called The Fruit, Vegetables and Root Crops Section. In that case potatoes, yams, cassava, carrots etc. were not included as vegetables, and many plants that are referred to as *root crops* are not e.g. potato where the edible part is stem tubers. Also edible fungi such as mushrooms are usually referred to as *vegetables*. Weichmann (1987) defines vegetables as 'any plant products that do not belong to the group of fruit or cereals and that are consumed fresh, raw or processed directly without substantial extraction (e.g. sugar from sugar beets)'. However, he includes several fruits e.g. tomatoes that appear to contradict his definition. For the purpose of this volume this scope will be accepted and any fresh plant product that is not commonly used as a fresh

fruit or cereal will be included. An interesting table was given by Mohan and Kalidass (2010) for the range of root and tuber crops that they collect from the wild in sandy loam soil consumed by the tribal Valaiyans in India showing the very wide range (Table 1).

Postharvest biology, physiology, chemistry, pathology and technology of fruit and vegetables are studied and practised essentially with the same objectives. These are to reduce losses and present them to the consumer in the condition they require at the time they require them. To achieve this basic research has been carried out to understand the chemical and physiological processes that occur postharvest in fruit and vegetables and the interactions with microorganisms that are present in or on them. Over the years there has been an increasing scientific and technological literature produced to address these issues, and yet quantitative and qualitative postharvest losses continue, in many cases at relatively high levels. Almost any postharvest loss figuring between zero and total loss may be found for fruit and vegetables. Losses may be related to technical considerations including cultivation practices, the cultivar, harvest maturity, packaging, handling system, and disease control, storage and transport conditions. They may also be related to the market where total losses may occur if the vegetable has lost its market because of over supply or bad planning or where it is deemed advantageous to remove it from the

Table 1 Wild edible tubers, rhizome, corm, roots and stems consumed by the tribal Valaiyans in India (source: adapted from Mohan and Kalidass 2010)

Botanical name	Plant parts used
<i>Aponogeton natans</i> (L.) Engler & K.	Tuber
<i>Boerhavia chinensis</i> (L.) Asch & Schweinf.	Root
<i>Caralluma adscendens</i> (Roxb.) Haw. var. <i>attenuata</i> (Wight) Grav. & Mayuranathan	Stem
<i>Caralluma pauciflora</i> (Wight) N.B.Br.	Stem
<i>Canna indica</i> L.	Stem
<i>Cissus quadrangularis</i> L.	Rhizome
<i>Cissus vitiginea</i> L.	Tuber
<i>Colocasia esculenta</i> (L.) Shott	Corm
<i>Cycas circinalis</i> L.	Tuber
<i>Cyphostemma setosum</i> (Roxb) Alston	Tuber
<i>Decalepis hamiltonii</i> Wight & Arn.	Tuber
<i>Dioscorea pentaphylla</i> L. var. <i>pentaphylla</i>	Tuber
<i>Dioscorea oppositifolia</i> L. var. <i>oppositifolia</i>	Tuber
<i>Dioscorea spicata</i> Roth.	Tuber
<i>Dioscorea tomentosa</i> Koen. Ex. Spreng.	Tuber
<i>Hemidesmus indicus</i> (L.) R. Br. var. <i>indicus</i>	Root
<i>Ipomoea staphylyna</i> Roem & Schultes	Root
<i>Kedrostis foetidissima</i> (Jacq.) Cogn.	Tuber
<i>Maerua oblongifolia</i> (Forsk.) A. Rich	Tuber
<i>Momordica diocia</i> Roxb ex Willd	Tuber
<i>Nymphaea pubescens</i> Willd	Tuber
<i>Nymphaea rubra</i> Roxb ex Andrews	Tuber
<i>Parthenocissus neilgherriensis</i> (Wight) Planch.	Tuber

market to manipulate price. The levels of these losses have been frequently estimated, and global figures are given in research papers and reports of national and international organizations involved in agriculture. What these estimates and measurements represent depends on:

- What the observers consider are losses e.g. economic, physical, cosmetic and nutritional.
- The specific conditions during the period between harvest and when the measurement or estimate was taken.
- The time taken between harvest and the measurement or estimate.
- The condition of the crop at harvest.
- The supply and demand situation at the time of the observation.

Masarirambi *et al.* (2010) reported that from developing countries such as Swaziland, the magnitude of postharvest losses of fruits and vegetables can reach up to 50%. Doumbia (1990) also reported that losses could be high especially in developing countries for

example cassava had postharvest losses estimated at 30% in Côte d'Ivoire. Weinberger *et al.* (2008) reported that postharvest loss of the selected vegetables along the supply chain in Vietnam, Cambodia and Laos was about 17%. Kitinoja *et al.* (2011) summarized many studies and concluded that farmers in developing countries have been losing between 30 and 40% of the value of their fruits and vegetables before they reach the final consumer. In Ethiopia the loss of vegetables between production and consumption was estimated to be 25–35% (Girma Abera Jibat, Horticultural Crops Production in Ethiopia). With fruit and vegetables it was conservatively estimated by Coursey and Booth (1977a) from the limited data to be found scattered in the literature, together with what might best be described as anecdotal information that the total loss is of the order of 25%. A case study in a medium-sized city in Brazil showed total wastage of fruit and vegetables to be 16.6% during marketing and 3.4% in household garbage (Fehr and Ramao 2001). A study of sweetpotatoes by Tomlins *et al.* (2000) in Tanzania showed that the handling and transport system resulted in up to 20% severe breaks and 86% skinning injury and a reduction in market value of up to 13%. In Jamaica only 49% of yams were suitable for export mainly because of the damage during transport from the field to the packhouse compared with 84% if they were handled carefully (Thompson 1972a).

Losses during storage are known to be high and, depending on the species and the storage environment, may be of the order of 30–60% during the course of 3–6 months (Coursey and Proctor 1975). The principal causes of loss include:

- Weight loss due to desiccation
- Loss of carbohydrate and water due to respiration
- Sprouting on breakage of dormancy
- Microbial decay, particularly as a result of the infection of wounds
- Losses due to rodents and insects.

The cause of desiccation is related to the humidity around the vegetable and can be controlled by reducing the loss of moisture from the air, injecting moisture into the air or reducing the velocity of the air passing the vegetable. In refrigerated storage desiccation is reduced if the refrigerant temperature is kept as close to the store air temperature as possible. Reducing the temperature around the vegetable can

reduce their respiration rate and thus reduce loss of carbohydrates and other chemicals. Sprouting can be controlled to some degree by reducing temperature but appropriate chemical application may be necessary. Most diseases are caused by infection with fungi that might occur in the field and develop postharvest. There are many species of fungi involved. Bacterial infections are also an important cause of losses. Bhat *et al.* (2010) reported that soft rot is primarily caused by *Erwinia carotovora* subspecies *carotovora* and sometimes by *E. carotovora* subspecies *atroseptica*. It is one of the most destructive diseases of vegetables and causes a greater total loss of produce than any other bacterial disease. Rodents and insects are significant contributors to postharvest losses but less so than microorganisms.

The quality of a crop at harvest can have a major effect on its postharvest life. There are numerous factors involved and these factors frequently interact giving complex inter-relationships. In tree crops, fruit produced on the same tree and harvested at the same time may behave differently during marketing or when stored. The issues that influence produce quality include obvious things, such as harvest maturity and cultivar or variety, but also the climate and soil in which it was grown, chemicals which have been applied to the crop, and its water status. Many of these factors can also interact with time such as when fertilizers or irrigation is applied or the weather conditions near to the time of harvest. Quality is an often-used word but rarely is there total agreement on what is meant by it. Quality can be viewed as the absence of defects or a degree of excellence. What is meant by quality can be different to different people involved in the postharvest chain. Probably the most suitable definition is simply their suitability for a particular use. It can also be defined as the extent to which the product comes up to the users expectations. The quality can be subdivided into emotional quality and analytical quality which may require sophisticated instrumentation to measure. The relative importance of different quality attributes can change from harvesting to use by the consumer. Most postharvest research, scientific and technological, assumes a product orientation to quality. Quality can also be considered a series of attributes selected on the basis of accuracy and precision of measurement. The difficulties that occur with product-orientated quality is that there can be a bias towards the more readily quantifiable attributes and

in many respects this approach to quality can be most effective in assessing changes in handling technique or postharvest treatment.

Quality standards have been developed and often have legal enforcement, some locally and some internationally. The Organisation de Coopération et de Développement Économiques in Paris published brochures of standards for example on pears in 1983 and on aubergines in 1987. Exporters and importers often impose other standards in international trade that are more detailed and comprehensive. An example is the banana export industry in the Windward Islands where they have produced detailed definitions of defects with tolerance levels (Table 2). They export almost exclusively to Europe and they must conform to their standards. The European regulations are the Commission Regulation [EC] No 2257/94 of 16 September 1994, which provide the quality standards and market requirements for bananas. Bananas must be harvested at a stage that will ensure a sufficient preclimacteric life for them to reach the ripening rooms before ripening has initiated. Leading exporters have their own standards that essentially exceed the requirements of the importing regulations. The Windward Islands also have a coding system that enables the grower and packer of each box of fruit to be identified throughout the marketing chain. These standards are agreed with the market representatives in the importing countries who frequently send representatives to inspect production and packing as part of their statutory duty of care. In grapes berry firmness, lack of infection, absence of defects including cracked berries, stem browning, shrivelling, sunburned and dried berries and insect damage are major factors that determine acceptability and price. An example of quality standards are those for India where AGMARK classified grapes into the following (Shikhamany 2008).

Extra class

Grapes must be of superior quality. Bunches must be typical of variety in shape, development and colouring and have no defects. Berries must be firm, firmly attached to the stalk, evenly spaced along the stalk and have their bloom virtually intact. A 5% tolerance by weight of bunches not satisfying the requirements of the grade is acceptable, but these must meet those

Table 2 Levels of defects allowed for Class 1 bananas in the Windward Islands.

Defect	Tolerance level per cluster	Defect	Tolerance level per cluster
Superficial bruise	Up to 0.4 inch ²	Finger end rot	0
Latex staining	Up to 0.4 inch ²	Fused fingers	0
Maturity stain	Up to 0.4 inch ²	Misshapen/malformed fingers	0
Pest damage	Up to 0.4 inch ²	Mutilated fingers	0
Red rust damage	Up to 0.4 inch ²	Over-grade	0
Scars	Up to 0.4 inch ²	Peel burn	0
Sooty mould	Up to 0.4 inch ²	Residue	0
Flower thrips	Up to 25%	Ripe and turning	0
Speckling/pin spotting	Up to 50%	Scruffy	0
Crown trimming	0	Short finger	0
Damaged pedicel/neck injury	0	Stale fruit	0
Dirty	0	Un-deflowered	0
		Under-grade	0

of class I grade or exceptionally coming within the tolerances of that grade. The minimum weight of bunches is 200 g for large fruit and 75 g for small fruit.

Class I

Grapes must be of good quality. Bunches must be typical of variety in shape, development and colouring. Berries must be firm, firmly attached to the stalk and, as far as possible, have their bloom intact. They may, however, be less evenly spaced along the stalk than in the extra class. A slight defect in shape or colouring may be present, providing these do not affect the general appearance of the produce and keeping quality of the package.

A 10% tolerance by weight of bunches not satisfying the requirements of the grade is acceptable, but these must meet those of class II grade or exceptionally coming within the tolerances of that grade. The minimum weight of bunches is 150 g for large fruit and 100 g for small fruit.

Class II

Bunches may show defects in shape, development and colouring provided these do not impair the essential characteristics of the variety. The berries must be sufficiently firm and sufficiently attached. They may

be less evenly spaced along the stalk than class I grade. Defects in shape or colouring, slight sun scorch affecting the skin only, slight bruising and slight skin defects may be there, provided these do not affect the general appearance of the produce and keeping quality of the package. A tolerance of 10% by weight of bunches not satisfying the requirements of the grade, but meeting the minimum requirements is acceptable. The minimum weight of bunches is 100 g for large fruit and 75 g for small fruit.

HACCP

Hazard Analysis Critical Control Point (HACCP) has become an increasingly important part of quality procedures and is generally considered an effective and rational means of assuring food safety and quality. The main objective of any HACCP system is to prevent problems occurring, so it is a systematic approach to the identification, evaluation and control of food hazards. One of the weaknesses of some HACCP plans is that once they have been developed they are not updated and so it is important to have a verification schedule to validate and review the procedures. Various organizations provide training in HACCP, and there are standards and examinations by organizations such as the Royal Institute of Public Health and Hygiene in the United Kingdom.

2

Health-promoting properties of fruit and vegetables

Human beings are omnivores, and plant material is a crucial part of the human diet. Fruit and vegetables are a source of the basic nutrients of proteins, carbohydrates, minerals and what are called phytochemicals. Keller and Tukuitonga (2007) wrote 'Low fruit and vegetable intake was identified as an important risk factor for chronic diseases in the WHO World Health Report 2002. Overall, it is estimated that up to 2.7 million lives could potentially be saved each year if fruit and vegetable consumption was sufficiently increased.' Fruit and vegetables were doubtless eaten for their flavour from time immemorial but their health and healing properties were also known. In the 18th century a French pharmacist Antoine-Augustin Parmentier demonstrated, for several years by his own diet, that all the nutrients required to sustain a healthy life were found in potatoes (Block 2008). The Chinese have long used parts of plants to prevent or control diseases. In the 1980s the term *functional foods* was first introduced in Japan and referred to foods that were nutritious and also contained chemicals that had health functions. They introduced a specific regulatory approval process called Foods for Specified Health Use. These foods were eligible to bear a Government seal of approval (Arai 1996). Besides the chemicals required for human nutrition, plant material contains what has been called phytochemicals. In 1988 the '5-a-day' portion of fruit

and vegetables campaign was initiated in the United States, and subsequent recommendations in other countries have been for different amounts. A portion was defined as 80 g or 150 ml of unsweetened fruit juice; although juice should contribute only one portion. WCRF/AICR (1997) recommended that the inclusion of 400–800 g of a variety of fruit and vegetables should be included in the diet to reduce the risk of cancer. In their subsequent review WCRF/AICR (1997) recommendations remained to include 'at least 5 portions/servings (at least 400 g day⁻¹) of a variety on non-starchy vegetables and of fruit each day', but this consumption may not be effective in reducing the risk of all cancers. However, in a UK survey more than 60% of adults had intakes below the recommended level of 400 g day⁻¹ (Ashfield-Watt *et al.* 2003). Of course this '5-a-day' recommendation can only be a generalization to give a simple indication and encouragement to people to eat more fruit and vegetables. The size and age of the person must affect their requirements as well as the portion that consists of peel and other parts that are not eaten. Often important phytochemicals are contained in the peel. A study in the USA showed that the concentration of flavonoids in fruit and vegetables consumed by the public was highly variable. Harnly *et al.* (2006) suggested that this was most likely due to different

Table 3 Amount of phenolic antioxidants from 150 g of selected fruit and vegetables (source: adapted from Tomás-Barberán and Gil 2008)

Fresh fruit or vegetable	Phenolic antioxidants intake	
	Cultivar	Phenolic antioxidants intake
Peach	Cultivar Snow King 110 mg not peeled	Cultivar Flavor Crest 15 mg peeled
Grape cultivar Napoleon	150 mg with seeds and peel	5 mg without seeds and peel
Orange cultivar Navel	400 mg with part of albedo	100 mg without albedo
Lettuce	300 mg cultivar Lollo Rosso leaving external leaves	10 mg cultivar Iceberg white midribs
Spinach	120 mg steam cooked	50 mg boiled and water removed

cultivars, local growing conditions and processing methods. In individual species and cultivars of fruit and vegetables there are a range of phytochemicals. For example bioactive phytochemicals in citrus fruits include limonoids, vitamin C, β -carotene, flavonoids, folic acid and dietary fibre (Silalahi 2002). Taking phenolics as an example Tomás-Barberán and Gil (2008) showed that there was a wide variation in chemical content of selected fruit and vegetables, their method of preparation and the parts that are consumed (Table 3).

Phytochemicals in fruit and vegetables

Besides the chemicals required for human nutrition, fruit and vegetables contain what has recently been referred to as *phytochemicals*. Of the thousands of phytochemicals only a limited number have been evaluated in terms of their effects on human health. Rice-Evans and Miller (1995), reviewing the literature on antioxidants, found that there was a strong case that they could contribute to the prevention or delaying the onset of cancer and heart diseases. Silalahi (2002) also found that there was strong evidence that there is a low risk of degenerative diseases, cardiovascular disease, hypertension, cataract, stroke and cancers in people with a high intake of fruit and vegetables. Antioxidants are substances that can prevent or delay oxidative damage of lipids, proteins and nucleic acids by reactive O_2 species. They scavenge radicals by inhibiting initiation and breaking chain propagation or suppressing formation of

free radicals by binding to the metal ions, reducing hydrogen peroxide and quenching superoxide and singlet O_2 . The most abundant antioxidants in fruits are polyphenols and ascorbic acid. Vitamins A, B and E and carotenoids are present to a lesser extent in some fruits. These polyphenols, most of which are flavonoids, are present mainly in ester and glycoside forms (Fleuriet and Macheix 2003). Jaganath and Crozier (2008) defined phytochemicals as 'bioactive non-nutrient plant compounds that have been linked to reductions in the risk of major chronic diseases'. They classified them into four groups:

- Nitrogen-containing alkaloids
- Phenolics and polyphenolics
- Sulphur-containing compounds
- Terpenoids

Classification is complicated and Best (2006) included the following as a first attempt at partial classification of some phytochemicals:

terpenoids = isoprenoids

- carotenoid terpenoids
 - lycopene
 - β -carotene
 - α -carotene
 - lutein
 - zeaxanthin
 - astaxanthin
- non-carotenoid terpenoids
 - perillyl alcohol
 - saponins
 - terpineol
 - limonoids

polyphenolics

- flavonoid polyphenolics
 - anthocyanins
 - catechins
 - isoflavones
 - hesperetin
 - naringin
 - rutin
 - quercetin
 - silymarin
 - tangeretin
 - tannins
- phenolic acids
 - ellagic acid

chlorogenic acid
 para-coumaric acid
 phytic acid
 ferulic acid
 vanillin
 cinnamic acid
 hydroxycinnamic acids
 • other non-flavonoid polyphenolics
 curcumin
 resveratrol
 lignan

glucosinolates

- isothiocyanates
 phenethyl isothiocyanate
 benzyl isothiocyanate
 sulforaphane
- indoles
 indole-3-carbinol

thiosulphonates

- phytosterols
- β -sitosterol

anthraquinones

- senna
 barbaloin = aloin
 hypericin

capsaicin

piperine

chlorophyll

betaine = trimethylglycine

pectin

oxalic acid

Functions of phytochemicals

There are many functions of phytochemicals that are not directly related to human health. They may provide colour or flavour or they may have phytoalexin or deterrent properties.

Pigmentation

Plants synthesize many different pigments that give them their characteristic colour. Anthocyanins give a red colour in many fruits e.g. strawberries, raspberries, cherries, cranberries, pomegranates, apples

and some grapes. In tomatoes, pink grapefruit, apricots, red oranges, watermelon, rose hips and guava, lycopene, a carotenoid in the same family as β -carotene, gives the red colour and in beetroot it is β -cyanins. In carrots, mangoes, apricots, cantaloupe melons, pumpkin and sweet potatoes, β -carotene gives the orange colour, but in oranges and mandarins β -cryptoxanthin gives the orange colour. Anthocyanins give a black to purple colour to blackberries, blueberries, plums, aubergines and some grapes. The yellow pigments in avocado and maize are lutein and zeaxanthin (Best 2006).

In kiwifruit Montefiori *et al.* (2005) found that the yellow and green colours of the outer fruit pericarp are due to different concentrations and proportions of carotenoids and chlorophylls. The red colour found mainly in the inner pericarp is due to anthocyanins. In *Actinidia chinensis* the major anthocyanin was cyanidin 3-o-xylo(1-2)-galactoside, with smaller amounts of cyanidin 3-o-galactoside. In *A. deliciosa* cyanidin 3-o-xylo(1-2)-galactoside was not detected; instead the major anthocyanins identified were cyanidin 3-o-galactoside and cyanidin 3-o-glucoside. However, the two species did not differ consistently in anthocyanin composition. Carmona *et al.* (2012) found an increased total carotenoid during storage of the orange cultivar Navelina at 12 °C and 90–95% r.h. for 7 weeks. Improvement of peel colour was mainly due to an increase in β -citraurin, and β -cryptoxanthin (provitamin A) was higher in the pulp of fruit stored at 12 °C than those stored at 2 °C.

In tomatoes chlorophyll levels are progressively broken down into phytol during ripening. It was observed that in cherry tomatoes the total chlorophyll content was reduced from 5490 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in green fruit to 119 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in fully red fruit (Laval Martin *et al.* 1975). They also found that total carotenoids in cherry tomatoes increased from 3297 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in green fruit to 11694 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in fully red fruit. Concurrent with this degradation process, lycopene, carotenes and xanthophylls are synthesized giving the fruit its characteristic colour usually red (Grierson and Kader 1986). This colour development occurred in both the pulp and the flesh of the tomato. The optimum temperature for colour development was 24 °C and at 30 °C and above lycopene was not synthesized.

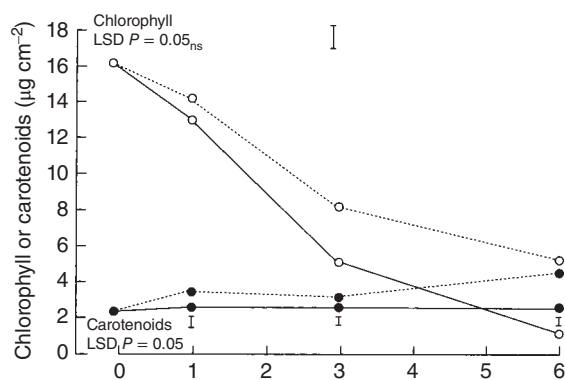


Figure 1 Changes in the pigment level of bananas during ripening at either 20 or 35 °C. The fruit were exposed to 1000 μL^{-1} before being ripened in air. (Source: Seymour 1985. Reproduced with permission.)

The pigments in the peel of bananas and plantains are chlorophylls, carotenoids and xanthophylls. The change in colour of ripening fruits is associated with the breakdown of chlorophylls with carotenoid levels remaining relatively constant in bananas (Figure 1). Cavendish banana cultivars can fail to completely degreen when they are ripened at 25 °C and above (Seymour *et al.* 1987b, Semple and Thompson 1988). This can result in bananas that are ripe in every other respect, retaining green peel. The higher the temperature is, the more obvious will be the effect, and it is one cause of the physiological disorder of Cavendish bananas called *pulpa crema*. This is where banana fruit are initiated to ripen on the plant, but because the ambient temperature is above 25 °C the pulp ripens but the chlorophyll in the skin is not fully broken down. With plantains it was shown that complete or almost complete chlorophyll destruction can occur even at 35 °C (Seymour 1985, Seymour *et al.* 1987a). Studies on why this effect of temperature on degreening of Cavendish bananas occurs failed to reach a definitive conclusion although there was some indication that it was related to the thylakoid ultrastructure of the chloroplasts (Seymour 1985, Blackbourn *et al.* 1990).

Fruit chlorophyll concentration was approximately 14-fold higher in black capsicum fruit in comparison to violet-coloured fruit that contained relatively little chlorophyll. β -Carotene, lutein, violaxanthin and neoxanthin carotenoid concentrations in black-coloured fruit were also significantly greater in comparison to violet-coloured fruit. High

concentrations of delphinidin in combination with chlorophyll and accessory carotenoid pigments produced the characteristic black pigmentation observed in fruits and leaves of selected genotypes. Anthocyanins were accumulated in the outer mesocarp of violet- and black-coloured fruit and in the palisade and mesophyll cells of black leaves (Lightbourn *et al.* 2008). Manning (1993) showed that auxin produced by the achenes of strawberries could affect the colour (anthocyanin production) of the ripening fruit. Removal of the achenes from developing strawberry fruit resulted in quicker colouring in the area where they were removed.

Flavour

Flavour is the subtle and complex perception combining taste, smell and texture or mouthfeel. It is essentially a combination of sugars, acids and phenolics and organic volatiles. The exact relationship between the chemistry and the flavour and aroma of fruit and vegetables has not been fully determined. McCarthy *et al.* (1963) claimed that amyl esters gave bananas their distinctive flavour and aroma, and butyl esters gave them a fruity flavour and aroma. However, besides the volatile compounds mentioned above, other esters, as well as aldehydes, alcohols and ketones, have been associated with fruit flavour, and their production rates can increase during banana ripening (Tressl and Jennings 1972). Sivakumar *et al.* (2008) found significant differences in aroma between two litchi cultivars, and they were able to link this with specific chemicals.

Toxicity

Tomatoes at the green stage of maturity contain the toxic glycoalkaloid solanine that decreases during ripening (Laval Martin *et al.* 1975). Ackee fruit (*Blighia sapida*) contain the toxin hypoglycin in the arils that gradually reduces as the fruit matures (Larson *et al.* 1994). The phytoalexin pisatin was found to increase in the pods of peas which were exposed to ethylene levels of 0.2–20 $\mu\text{L L}^{-1}$ (Chalutz and Stahman 1969). Carrots exposed to ethylene can produce isocoumarin, which gives them the bitter flavour (Lafuente *et al.* 1989).

Synthesis of chlorophyll will occur when potato tubers are exposed to light. Glycoalkaloids may also

be synthesized but the formation of chlorophyll and glycoalkaloids are independent processes. The highest levels of glycoalkaloids are found in the periderm and cortex; hence about 60% will be removed by peeling (Rastovski and Van Es 1981). The limit for safe human consumption of α -chaconine and total glycoalkaloids were given as 200 mg kg⁻¹ fresh weight (Tan and Haynes 1996). The total level of glycoalkaloids varies widely among cultivars. In the breeding line WB8003-3 glycoalkaloids were not present and did not appear following illumination (Mori and Kozukue 1995). Storage of tubers at 7 °C and 95–98% for 90 days resulted in lower α -chaconine and solanine than in tubers stored at ambient, but levels fluctuated and were generally lowest at 60 days then increased towards the end of storage (Abdel Gawad *et al.* 1992). In contrast the cultivars Brodick and Pentland Crown exposed to 4 °C within 2 weeks of harvest resulted in a relatively rapid accumulation of glycoalkaloids to levels close to or exceeding the recommended safe maximum, while the cultivars Eden and Torridon appeared insensitive to cold stress (Griffiths *et al.* 1998). Storage for 6 weeks of all six cultivars studied at 4 °C produced over twice the amount of glycoalkaloids as those stored at 10 °C.

Exposure of potatoes to low O₂, especially at high temperatures of 25 °C or more, can result in necrotic cells being produced in the centre of the tuber. This is called blackheart and the cells contain melanin in both the protoplasm and the cell walls. Chlorogenic acid and tyrosine tend to accumulate in affected areas and the state and distribution of lipids changes (Reeve 1968). Undesirable flavours were reported in sweet potatoes exposed to ethylene in storage (Buescher *et al.* 1975). Fruit and vegetables exposed to stress can respond by producing chemicals, but Tomás-Barberán and Espin (2001) stated that many of them are in such small quantities that they have little or no significance in the human diet.

Oxalic acid is corrosive and is a common component of plants, particularly their leaf blades where it can reach relatively high concentrations e.g. in rhubarb and sorrel. Oxalic acid also forms salts e.g. calcium oxalate whose crystals may result in kidney disorders, gout and rheumatoid arthritis.

Ascorbic acid may be found throughout plant cells where it is known to be involved in cell division and cell wall synthesis and also acts as an inhibitor of

potentially toxic compounds and the dangerous radicals of oxygen generated as by-products of respiration and photosynthesis.

Fungi and bacteria infecting crops can have health implications. The most common mycotoxin is aflatoxin, which is produced by *Aspergillus flavus* and *A. parasiticus*. They have been shown to infect dozens of food products including groundnut kernels, coconut, wheat, rice, flour, dry beans and some leafy vegetables. Aflotoxins are highly toxic and carcinogenic. Patulin, which has carcinogenic properties, is produced in apples and pears as a result of infections by *Penicillium patulum*, *P. expansum*, *P. urticae*, *Aspergillus clavatus* or *Byssoschlamys nivea*. Several bacteria infecting vegetables can produce toxins including *Escherichia coli*, *Salmonella typhimurium*, *Clostridium botulinum*, *Listeria monocytogenes*, *Shigella* spp. and *Aeromonas hydrophila*.

Mandrake (*Mandragora officinarum*) is an ancient mystical plant whose attributes include healing all kinds of diseases, aiding love affairs as well as being used in witchcraft and other dark arts. There is no evidence of its health properties. It was mentioned by Shakespeare and Pliny who described how those who harvested them kept their backs to the wind then made three circles round the plant with the point of a sword. Often the soil would be loosened round the plant which was then tied to a dog to pull it from the ground.

Phytochemicals effects

Terpenoids

The terpenoids (terpenes and isoprenoids) include monoterpenoids and sesquiterpenoids that are mainly aromatic compounds that exist as essential oils whose main function are to protect the leaves from herbivores and attract insect pollinators. These include limonene in some *Citrus* spp. and menthol in some *Mentha* spp. They also function as antioxidants, protecting lipids, blood and other body fluids from being attacked by free radical oxygen. They neutralize free radicals because they have a long carbon side chain which anchors them into fatty membranes and thus restricts any free radicals attaching to lipid membranes and leaves them vulnerable to being attacked by other antioxidants. Diterpenoids include some compounds that act as phytoalexins

in cereals and are also found in the resin of some conifers as well as the plant growth regulators called gibberellins (Jaganath and Crozier 2008).

There are more than 600 naturally occurring carotenoids. They are a lipid-soluble subclass of terpenoids, which are synthesized in chloroplasts and are essential to the integrity of the photosynthetic apparatus (Tanaka and Nobuhiro Ohmiya 2008). One group is the 40-carbon tetraterpenes, which includes β -carotene. Among the carotenes, only α -, β - and ϵ -carotenes possess vitamin A activity, with β -carotene the most active. Another group, xanthophylls, includes the chemical compounds known as the carotenoid alcohols and keto-carotenoids including zeaxanthin, cryptoxanthin and astaxanthin. Xanthophylls appear to protect vitamin A, vitamin E and other carotenoids from oxidation. Lycopene is the primary carotenoid in tomatoes whose antioxidant function has been shown to offer protection against lung, colorectal, breast, uterine and prostate cancers.

In bananas carotenoid content remains constant during ripening, while in plantains they increased (Figure 1). Medlicott (1985) identified 10 carotenoids in mangoes and showed that overall these increased during ripening, but some individuals actually decreased (Table 4, Figures 2 and 3).

Vitamin A is an organic compound that has a major contribution to human health. It plays an important role in vision, cell growth and the regulation of the immune system. Like other vitamins, it cannot be

synthesized in sufficient quantities by the body and must be obtained from the diet. Plants do not contain vitamin A but some carotenoids can be converted into vitamin A during human digestion and are called provitamin A carotenoids (*pVACs*). In meat retinol is the main form of vitamin A. Measurement of *pVAC* is commonly related to retinol activity equivalent (RAE). The RAE is a relatively new unit for expressing vitamin A activity. One microgram of RAE is equivalent to 1 μg of all-*trans*-retinol, 12 μg of all-*trans*- β -carotene or 24 μg of other provitamin A carotenoids. RAE is therefore a unit used for quantifying the vitamin A value of sources of vitamin A, including both preformed retinoids in animal foods and precursor carotenoids in plant foods. It is defined as 3.3 international units of vitamin A.

Limonoids are non-carotenoid terpenoids which are common in citrus fruits peel (Silalahi 2002) and appear to give specifically protection of lung tissue (Hasegawa and Miyake 1996).

Phytosterols

Sterols are present in small quantities in many fruits and vegetables and are components of plant membranes (Piironen *et al.* 2003). Green and yellow vegetables contain significant amounts of phytosterols which are concentrated in their seeds. They block the uptake of cholesterol (to which they are structurally related) and facilitate its excretion from the body but levels are probably insufficient in plants to have appreciable effects in the human diet.

Phenols

Phenols protect plants from oxidative damage and perform similar functions for humans. Blue, red and violet colorations seen in berries, grapes and purple aubergines are due to their phenolic content, e.g. bilberries are high in phenolic anthocyanidins.

Flavonoids (bioflavonoids) are important phenols. The first flavonoids were identified in 1936 by Albert Szent-Györgyi, and currently over 4000 flavonoids of this phenol subclass have been identified and they include:

- Flavones containing the flavonoid apigenin are found in chamomile (*Chamomilla recutita*) and genistein in legumes.

Table 4 Characterization and quantitative distribution of the major carotenoids in the peel of Tommy Atkins mangoes (source: adapted from Medlicott 1985)

Carotenoid	% of total carotenoids	
	Unripe	Ripe
Antheraxanthin	5.1	4.5
Auroxanthin	4.8	12.5
Cryptoxanthin	9.4	2.1
Lutein	3.0	2.8
Luteoxanthin	5.1	6.7
Mutatochrome	5.2	6.2
Mutatoxanthin	4.1	2.7
Neoxanthin	1.4	0.9
Violaxanthin	4.9	5.8
β -Carotene	27.7	55.1
Total carotenoids	1.13 $\mu\text{g cm}^{-2}$	5.41 $\mu\text{g cm}^{-2}$

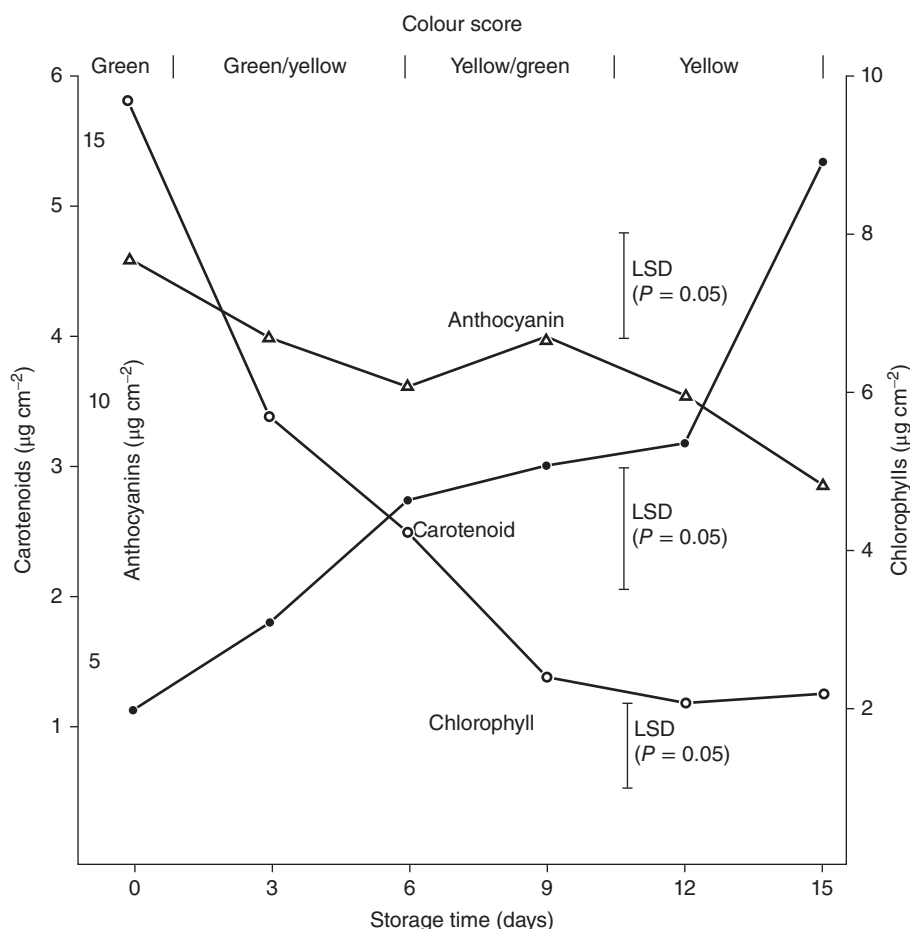


Figure 2 Changes in mangoes during ripening. (Source: Medlicott 1985. Reproduced with permission.)

- Flavonols containing quercetin are found in *Allium* spp., lemons, limes and grapefruits and rutin in buckwheat, lemons, limes and grapefruits.
- Flavanones containing hesperidin are also found in *Citrus* spp.

Flavonoids may also be classified into:

Antioxidant flavonoids

- Quercetin (a flavonol in vegetables, fruit skins and onions)
- Xanthohumol (a prenylated chalcone in hops and beer)
- Isoxanthohumol (a prenylated flavanone in hops and beer)
- Genistein (an isoflavone in soya bean)

Pro-oxidant flavonoids

- Chalconaringenin (a non-prenylated chalcone in citrus fruits)
- Naringenin (a non-prenylated flavanone in citrus fruits)

The benefits flavonoids have against cancer and cardiovascular diseases are the result of mechanisms other than antioxidant activity. It was hypothesized that they can stimulate processes in human cells that kill cancer cells and inhibit tumour invasion. Flavonoids are of little direct antioxidant value as less than 5% is absorbed and most of that is quickly metabolized and excreted from the body (Lotito and Frei 2006). The capacity of flavonoids to act as antioxidants depends upon their molecular structure. The position of hydroxyl groups

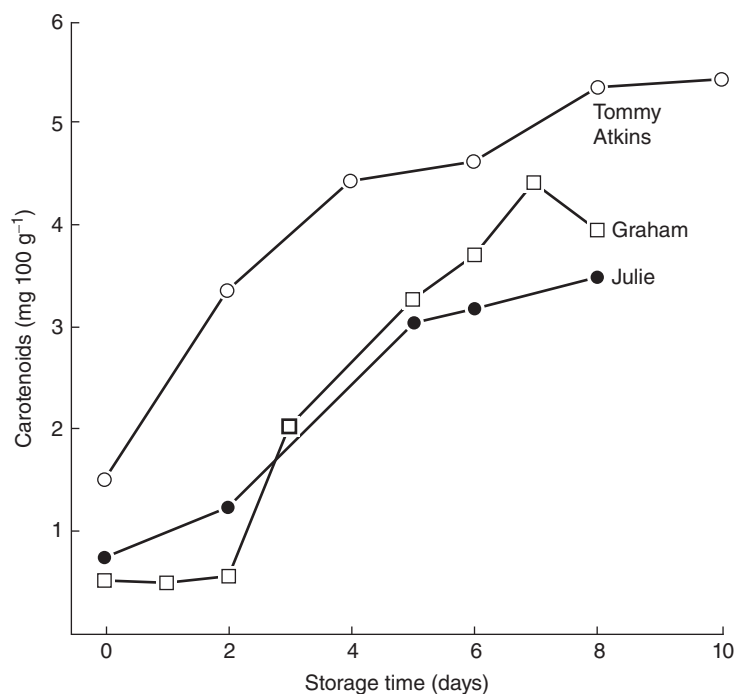


Figure 3 The effects of variety on changes in mangoes during ripening. (Source: Medicott 1985. Reproduced with permission.)

and other features in their chemical structure are important for their antioxidant and free radical scavenging activities. Quercetin, the most abundant dietary flavonol, is a potent antioxidant because it has all the right structural features for free radical scavenging activity. The biological activities of flavonoids include action against allergies, inflammation, free radicals, hepatotoxins, platelet aggregation, microbes, ulcers, viruses and tumours, and they can inhibit specific enzymes and help improve cardiovascular health and can enhance the effects of ascorbate/vitamin C.

Anthocyanins, a group of flavonal flavonoids, are widely distributed in plants and are water soluble, synthesized in the cytosol and localized in vacuoles. They give plants a wide range of colours, which depends on various modifications to their structures, co-pigments, metal ions and pH (Tanaka and Nobuhiro Ohmiya 2008). Some of the specific flavonoids in cherries include anthocyanins, proanthocyanins and anthocyanidins. Tart cherries are a rich source of anthocyanins (Craig 1997). In Finland Latti *et al.* (2008) found 15 anthocyanins in bilberries

with a mean content of total anthocyanins of 2878 mg 100 g⁻¹ dry weight. There was extensive variation in the anthocyanin contents with the delphinidin glycosides most common in berries from northern areas and the cyanidin glycosides most common in the berries from southern areas. Anthocyanidins are the aglycones of anthocyanins e.g. cyanidin, delphinidin, malvidin, pelargonidin, peonidin and petunidin. Anthocyanidins are also water soluble and scavenge free radicals in tissue fluids. In tubers of 38 native potato cultivars the total carotenoid content was negatively correlated with total anthocyanins (Brown *et al.* 2007). The content of anthocyanins during the ripening of mangoes tended to decrease while carotenoid content increased (Figure 2).

Catechins are another group of flavonoids in green tea and, to a lesser extent, black tea. Catechins differ slightly in chemical structure from other flavonoids. The most common are the gallic esters epicatechin, epicatechin gallate and epigallocatechin gallate. They are thought to be responsible for the health benefits of tea. Epicatechin is also the major endogenous polyphenols in litchi pericarp (Liu *et al.* 2007).

Isoflavones are a phenol subclass that are common in legumes and can function much like flavonoids, in that they effectively block enzymes that promote tumour growth. Isoflavones include glycitein and genistein and daidzein found in soya bean products. They function as antioxidants and they appear to possess properties that distinguish them from other types of flavonoids (Potter 1998).

The stilbene resveratrol is a non-flavonoid polyphenolic that is present in grapes and has been demonstrated to help prevent cancer and cardiovascular diseases (Cantos *et al.* 2000).

Glucosinolates

Glucosinolates produce a variety of hydrolysis products including isothiocyanates and indoles. They are powerful activators of liver detoxification enzymes and also regulate white blood cells and cytokines. They are a group of glycosides stored within cell vacuoles of cruciferous plants and Verhoeven *et al.* (1997) attributed the anticarcinogenic properties of some cruciferous plants to their relatively high content of glucosinolates. Fahey *et al.* (1997) demonstrated that broccoli sprouts contained high levels of glucoraphanin (the glucosinolate of sulphoraphane).

Some indoles interact with vitamin C. Indole complexes bind chemical carcinogens and activate detoxification enzymes. The bio-transformation products of indoles are formed in the stomach including ascorbigen which is considered to be an active vitamin C metabolite. Other compounds that have similar effects include allicin from garlic, indoles from broccoli, lycopenes from tomatoes and chlorophyll from leaf vegetables.

Capsaicin

Capsaicinoids occur in the fruit of chillies and are potent antioxidants that have anti-cancer activity (Surh and Sup Lee 1995). However, they are mainly used to season food as they have a strong pungency and react with receptors in the mouth to give a sensation of heat. Chillies may be classified by the concentration of capsaicin or capsicutin ($C_{18}H_{27}NO_3$) which determines their hotness.

Chlorophyll

Chlorophyll is ubiquitous in plants; Ferruzzi *et al.* (2001) demonstrated the uptake of chlorophyll

derivatives by human intestinal cells and the potential importance of chlorophylls as health-promoting phytochemicals.

Ginsenosides

Ginsenosides are found in the root of ginseng (*Panax ginseng*). Fatty alcohols in ginseng include falcari-nol, panaxacol, panaxydol and panaxytriol. In Chinese and Korean medicine ginseng has been used for millennia and is taken specifically to normalize blood pressure and blood sugar, as a sexual tonic and stimulant. Claims on their medical and health benefits have not always been consistent, but in studies of rats it was shown to reduce the incidence of cancers (Yun *et al.* 2001).

Pectins

Pectin is a family of galacturonic acid-rich polysaccharides in plant cell walls that can have positive effects on human health. Gunning *et al.* (2008) found modified pectin releases a molecular fragment (galactan) that curbs all stages of cancer progression. They found that when prostate cancer cells were exposed to pectin powder or heat-treated citrus pectin up to 40% died.

Piperine

Black pepper (*Piper* spp.) is a condiment used to flavour foods which contains piperine. Piperine has been shown to significantly increase the absorption of selenium, vitamin B and β -carotene during digestion and supports and assists the body's natural thermogenic activities (Cochran Foundation 2008).

Betaine

Increased levels of homocysteine, a breakdown product of methionine, have been found in patients with coronary artery and cerebrovascular disease, and betaine is a methyl donor that is involved in converting homocysteine back to methionine. Betaine stimulates the function of liver cells and protects the liver and bile ducts (Vogel 1991). Dietary sources of betaine include members of Chenopodiaceae, particularly beets, spinach and broccoli.

Vitamins

Vitamins are a diverse group of phytochemicals that are grouped because of their importance in the human diet and not by their chemical structure. They are essential to human health and are obtained from the diet, principally from fruit and vegetables, and also cereals, fish and meat; therefore their postharvest stability during storage and marketing is crucial. The exception is vitamin D that can be synthesized in the human body with some 90% from sunlight. Vitamins are also involved in the control and prevention of human diseases, for example vitamin C, one of the most important nutritional factors in fruit, has been found to prevent the formation of N-nitroso compounds, the cancer-causing substances from nitrates and nitrites found in preserved meats and some drinking water (Du *et al.* 2009).

Changes in phytochemicals in fruit and vegetables

The levels of phytochemicals in fruit and vegetables depend on cultivar, production factors (climate, soil, cultivation conditions and harvesting) and postharvest factors (temperature, humidity, gaseous environment, packaging and radiation). Other factors can influence their nutritive value including method of preparation or cooking and the parts that are consumed.

Cultivar

There is considerable variation in phytochemicals in different varieties and cultivars of the same species. The major anthocyanins present in two cultivars of litchi were cyanidin-3-rutinoside and cyanidin-3-glucoside. Although the concentration of cyanidin-3-rutinoside was 64% lower in 'Kwai May' than in 'Wai Chee', cyanidin-3-rutinoside represented more than 90% of total anthocyanins in both cultivars (Ducamp-Collin *et al.* 2008). Brown *et al.* (2007) found very high variation in phytochemicals in native South American potato varieties. In tubers of 38 native potato cultivars the total anthocyanins ranged from 0 to 23 mg cyanidin equivalents 100 g⁻¹ fresh weight, total carotenoid ranged from 38 to 2020 µg zeaxanthin equivalents 100 g⁻¹ fresh weight. Du Pont *et al.* (2000) showed variation in

phytochemicals in lettuce e.g. the cultivars Iceberg and Butterleaf had low levels of flavonoids and the cultivars Lollo Rosso and Oak Leaf had much higher levels and also contain high levels of anthocyanins. They also found that loss of flavonoid glycoside in lettuce and endive varied between cultivars during 7 days of storage at 1 °C. In a comparison between two litchi cultivars citronellol and geraniol were predominant in the aroma profile of the cultivar Mauritius and conferred characteristic floral, rose, citrus and fruity aromas, they also had higher ascorbic acid but lower anthocyanin concentration than McLean's Red. In McLean's Red, germacrene D was predominant in the aroma profile (Sivakumar *et al.* 2008). Davey *et al.* (2007) found that apple cultivars differed substantially in their ability to maintain L-ascorbic acid levels during storage, primarily owing to the loss of L-ascorbic acid by 'low-vitamin C' cultivars. MacLean *et al.* (2006) showed variable antioxidant capacity of four apple cultivars as follows: McIntosh (green skin) 1314, McIntosh (red skin) 1497, Delicious (red) 2182 and Empire 1096 µg g⁻¹ fresh weight.

Bilberries are a rich source of anthocyanidin glucosides, but some individual plants in wild populations were found with very low amounts (Latti *et al.* 2008). Medlicott (1985) showed differences in carotenoid levels in different mango varieties and the higher the level at harvest was, the more was synthesized during ripening (Figure 3).

There is growing interest in breeding new cultivars with specific phytochemicals. It is possible to improve the antioxidant action of tomatoes by increasing the production of flavonoids by genetic modification including the synthesis of specific flavonoids that they are not produced naturally by tomatoes (Schijlen 2008).

Water relations during growth

Water relations during growth can affect chemical content. Carr (1979) summarized the effects of irrigation on fruit and vegetable quality and concluded, with some reservations, that in most fruit and vegetables some water stress during growth can improve their flavour and some biochemical components. But conversely water stress may detrimentally affect appearance, succulence and fibre content. Stanhill (1957, quoted by Carr 1979) described an experiment where carrots which had not been watered had a

stronger flavour, smoother texture and deeper colour than those that had been watered. Vega Pina *et al.* (2000) found that if mango trees had a water stress for 45 days before flowering the fruit had a higher incidence and severity of internal darkening, but were firmer, had higher TA and redder skins than fruits with less severe water stress. Tovar *et al.* (2002) found that the level of total phenolics was related to irrigation levels in olives where they decreased with increasing amounts of irrigation.

Fertilizer application during growth

Taber *et al.* (2008) showed that potassium fertilization can affect carotenoid biosynthesis in tomato and their response to a high potassium rate is genotype dependent. There was a linear response in fruit potassium content from 1236 to 1991 mg kg⁻¹ (fresh weight basis) to potassium fertilizer applications as KCl of 0–372 kg ha⁻¹. Overall, the cultivar Fla. 8153 contained 9.5 mg kg⁻¹ more lycopene in fruit tissue than Mountain Spring. The concentration of lycopene in Mountain Spring was not increased by higher potassium fertilization (44.2 mg kg⁻¹). Fla. 8153 lycopene concentration increased 21.7% at the highest potassium rate (62.9 mg kg⁻¹) compared with lower rates (51.7 mg kg⁻¹).

No quality differences were found between blackcurrants grown organically or non-organically within a climatically similar area (Anttonen and Karjalainen 2006). Bourn and Prescott (2002) in a review of organic and non-organic productions on the nutrient value of food found that results were not consistent although there was some indication that organic crops contained lower levels of nitrate. This difference in nitrate level could be related to the high use of nitrogen fertilizer in non-organic production. Many phytochemicals contain nitrogen.

Harvest maturity

Harvest date had no effect on fruit lycopene concentration of tomatoes (Taber *et al.* 2008). Wold *et al.* (2007) showed that green unripe tomatoes contained considerably less antioxidants than ripe fruits. Harvest maturity can have an influence on nutrient levels. Petit pois peas have much lower protein, carbohydrate and vitamins A, B1 and B2 than more

mature peas, but many consumers prefer the texture and flavour of the less mature peas (Kramer 1979).

Total flavonoid and phenolic concentrations and total antioxidant activity of strawberries harvested at the white tip stage were greater than those harvested at the red ripe stage. These differences were maintained during the storage, except for red ripe fruit, where concentrations and activity decreased rapidly by day 12 in fruit stored at 10 °C, especially at 95% r.h. compared to lower humidity. Total ascorbic acid concentrations of white tip fruit were lower than in red ripe fruit at harvest, but increased slightly over time, while those in red ripe fruit were relatively stable until they decreased at 10 °C at day 12 (Shin *et al.* 2008). Ripe acerola and pitanga had two to three times greater β -carotene and lycopene than partially ripe fruit (Rodriguez-Amaya *et al.* 2007). The age of leaves can affect their chemical content for example in kale where β -carotene and lutein were higher in the mature leaves, while violaxanthin was higher in the young leaves. In endive and lettuce, carotenoids were two to four times higher in the mature leaves, but the young leaves of New Zealand spinach had higher carotenoid levels than the mature leaves (Rodriguez-Amaya *et al.* 2007).

In apple fruit there was a strong correlation between the date of harvest and the mean vitamin C (L-ascorbate and L-ascorbic acid) and total antioxidant activities but not with glutathione (Davey *et al.* 2007). Late season apple cultivars had the highest vitamin C content, while the lowest were the early cultivars. Knee and Sharples (1979) found that chlorophyll content of the cultivar Cox apples reduced rapidly if left of the tree after their normal harvest time. If they were harvested and stored in controlled atmosphere conditions chlorophyll content remained the same or only reduced slightly over a 6-month storage period.

Storage

Carbohydrates are lost rapidly when the fruit and vegetables are subject to conditions which increase their respiration rate. Other postharvest nutritional losses were shown by Alighourchi *et al.* (2008) who found that the mean degradation percentage of the 15 pomegranate anthocyanins studied was between 23 and 83% during 10 days at 4 °C. Antioxidant activity increased during storage of four Italian apple

cultivars which correlated with an increase of the concentration of catechin and phloridzin (Napolitano *et al.* 2004). The flesh of 'Annurca' apples has antioxidant properties comparable to those in the peel and polyphenolic compounds are relatively stable in the peel and the flesh, which should be maintained during long-term storage (D'Angelo *et al.* 2007).

Experiments on lettuce stored for 15 days showed that storage at 10 °C affected their leaf quality with significant chlorophyll reduction after only 5 days. Total carotenoids significantly decreased after 8 days, but there were no significant changes in anthocyanins and total phenols over the 15-day storage period (Ferrante and Maggiore 2007). Fahey *et al.* (1997) demonstrated that 3-day-old broccoli sprouts contained 10–100 times higher levels of glucoraphanin than did corresponding mature plants. Sugar levels of carambola remained constant during storage, although fruits continued to lose chlorophyll and synthesize carotenoids (Wan and Lam 1984). Perkins-Veazie *et al.* (2008) found that total anthocyanin, total phenolics, and ferric-reducing antioxidant power increased in blueberry fruit during storage at 5 °C for 7 days plus 2 days at 20 °C and 90% r.h. Several cultivars of orange stored at 6 ± 1 °C for 65 days by Rapisarda *et al.* (2008) had reduced flavanone concentration, but increased vitamin C in blond cultivars. Antioxidant activity increased during storage caused mainly by phenolic accumulation in blood cultivars and vitamin C increase in blond cultivars. Stevens *et al.* (2008) found reduced ascorbic acid levels of tomato fruit following storage at 4 °C. In broccoli the antioxidant activity and L-ascorbic acid content increased during 4 weeks of storage at 5 °C (Wold *et al.* 2007). Storage at 0 °C induced an accumulation of anthocyanin in the skin of grapes (Romero *et al.* 2008). Total carotenoids in cherry tomatoes increased from 3297 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in green fruit to 11694 $\mu\text{g } 100 \text{ g}^{-1}$ fresh weight in dark red fruit (Laval Martin *et al.* 1975). This colour development occurred in both the pulp and the flesh of the tomato. Rapisarda *et al.* (2008) evaluated eight citrus cultivars and found an increase in anthocyanins, flavanones and hydroxycinnamic acids and a slight decrease in vitamin C in the blood oranges during storage at 6 ± 1 °C for 65 days. Cold storage negatively affected flavanone concentration, while it positively influenced vitamin C in blond orange cultivars. There was an increase in antioxidant capacity during

cold storage caused mainly by phenolic accumulation in blood oranges and vitamin C increase in blond oranges.

Storage temperature

Storage temperature can affect fruit chemistry. Lana *et al.* (2005) showed that lycopene in tomatoes increased during storage at 8 or 16 °C, while at lower temperatures there was no change or a slight decrease. The optimum temperature for colour development in tomatoes is 24 °C, at 30 °C and above lycopene is not formed (Laval Martin *et al.* 1975). The mean ascorbic acid level in pineapples was 18.8 mg 100 g^{-1} in fruit that had been stored at 10 °C for 21 days followed by 48 h at 28 ± 2 °C compared with 9.3 mg 100 g^{-1} in fruit stored at 28 ± 2 °C for the full 23 days (Wilson Wijeratnam *et al.* 2005). Also in pineapples Zhou *et al.* (2003) showed that an increase in polyphenoloxidase activity was related to the incidence of blackheart. Immature and over-mature fruits developed less blackheart than mature fruit and it was related to storage at 6–18 °C and did not occur at 25 °C. Ferrante and Maggiore (2007) found that storage at 10 °C affected lettuce leaf quality. Significant chlorophyll reduction was observed after only 5 days of storage. Total carotenoids significantly decreased after 8 days at both 4 and 10 °C. Anthocyanins and total phenols did not change significantly during the entire experimental period at either temperature. The level of total phenolics was stable in broccoli during storage for 7 days at 5 °C (Leja *et al.* 2001). Schotsmans *et al.* (2007) reported an increase in anthocyanins content of blueberries and Goncalves *et al.* (2004) a similar effect in cherries and Cordenunsi *et al.* (2005) for strawberries, all during ambient temperature storage. Tomás-Barberán and Espin (2001) found an increase in the anthocyanins content of blueberries, grapes, pomegranates and strawberries during cold storage. Broccoli heads were stored at temperatures of 1 or 4 °C and 99% r.h. for up to 28 days but no deleterious effect on the levels of aliphatic glucosinolates and flavonols was found (Winkler *et al.* 2006). Du Pont *et al.* (2000) found up to 46% loss of flavonoid glycoside content in lettuce and endive after 7 days of storage at 1 °C. Perkins-Veazie *et al.* (2008) found that total anthocyanin, total phenolics and ferric-reducing antioxidant power increased in

blueberry fruit during storage at 5 °C for 7 days plus 2 days at 20 °C with 90% r.h.

Storage humidity

Shin *et al.* (2008) found no differences between 65 and 95% r.h. in colour change, flavonoid and phenolic concentrations, and total antioxidant activity during 12 days of storage of strawberries. Somboonkaew and Terry (2011) found that there were no significant effects of humidity, over the range of 80–100% r.h., on the loss of sugars in litchi during 9 days of storage at 13 °C but all three of the anthocyanins they measured decreased except in fruit stored at 100% r.h. where they increased.

Controlled atmosphere storage

The flavour of fruits is partly determined by their sugar and acid content. The sugar level in apples is mainly determined by the levels of starch and sugar at harvest since losses due to respiration is no more than 10% (Knee and Sharples 1979). However, they found that acidity could fall by as much as 50% during storage and that there was a good correlation between fruit acidity and sensory evaluation. Controlled atmosphere storage of apples in either 2% O₂ + 98% nitrogen or 2% O₂ + 5% CO₂ + 93% nitrogen resulted in few organic volatile compounds being produced during the storage period (Hatfield and Patterson 1974). Even when the fruit were removed from storage they did not synthesize normal amounts of esters during ripening. In apples and pears butyl ethanoate, 2-methyl butyl ethanoate and hexyl ethanoate are typical flavour and aroma compounds that are synthesized during ripening, while terpenoid compounds such as linalool, epoxide and farnesene have been shown to be synthesized in some apple cultivars (Dimick and Hoskins 1983). Leja and Ben (2003) found a large increase in total phenolics in Jonagold and Sampson apples during storage for 120 days at 1 °C in air or 2% O₂ + 2% CO₂ followed by 7 days at 16 °C. They actually found a slight decrease in anthocyanins during storage in air but not in the controlled atmosphere. In contrast MacLean *et al.* (2006) detected no change in total phenolics of Red Delicious apples during storage for 120 days at 0–1 °C followed by 8 days at room temperature, but there was an increase in chlorogenic

acid and a decrease in anthocyanins. In 'Rocha' pears stored for 4 months in 2% O₂ + 0–5% CO₂ at 2 °C. Goodenough and Thomas (1981) showed that tomatoes ripened in 5% CO₂ + 5% O₂ had suppressed chlorophyll degradation and suppressed synthesis of the carotenoids lycopene and xanthophyll. In apples reducing the O₂ level predominantly inhibited chlorophyll degradation. TA was highest in 15% O₂ + 10% CO₂ and 5% CO₂ + 3% O₂ (Ben-Arie *et al.* 1993). Galvis-Sanchez *et al.* (2006) found no differences between storage atmospheres on the phytochemical content they measured in pears, but arbutin and flavan-3-ols increased, while flavanols and hydroxycinnamic acid derivatives did not change in all atmospheres they studied. Martínez-Sánchez *et al.* (2006) found that the total flavonoid content of wild rocket (*Diplotaxis tenuifolia*) was approximately 100 mg 100 g⁻¹ fresh weight and remained constant during storage or even increased at the end of the shelf life in 5% O₂ + 10% CO₂. In contrast it was degraded in those samples kept in air, and the total content of vitamin C was higher in controlled atmosphere stored samples than those kept in air. A decrease in the total antioxidant capacity was observed during storage and it was particularly marked in samples stored in air.

Jeffery *et al.* (1984) showed that lycopene synthesis in tomatoes was suppressed during storage in 6% CO₂ + 6% O₂. Rogiers and Knowles (2000) stored four cultivars of *Amelanchier alnifolia* at 0.5 °C for 56 days in 2, 10 and 21% O₂ factorially combined with 0.035 or 5% CO₂. They found that the 5% CO₂ atmosphere combined with either 21 or 10% O₂ was most effective at minimizing losses in soluble solids, anthocyanin, firmness and weight of fruit. In blueberries controlled atmosphere storage had little or no effect on phenolic content (Schotsmans *et al.* 2007). Zheng *et al.* (2003) found that total phenolics were increased in blueberries during storage at 5 °C in 60–100% O₂ for 35 days to a greater extent than those stored in air or 40% O₂. In grapes anthocyanin levels were lower after storage at 0 °C for those that had been pretreated for 3 days in 20% CO₂ + 20% compared to those that had not been pretreated (Romero *et al.* 2008). Storage of snow pea pods in either 2.5% O₂ with 5% CO₂ or 10% CO₂ with 5% O₂ concentrations resulted in the development slight off-flavours, but this effect was reversible since it was partially alleviated after ventilation (Pariasca *et al.* 2001).

Ethylene

Exposing harvested fruit and vegetables to ethylene can stimulate respiration rate, initiate climacteric fruit to ripen and can result in the rapid breakdown of chlorophyll (Thompson and Seymour 1982). This effect has been shown on a wide variety of crops including celery, cucumbers, cabbage, Brussels sprouts, cauliflower leaves, capsicums, tomatoes, broccoli and citrus fruits (Thompson 2003). Application of ethylene to stored tomatoes was shown to increase their carotenoid and lycopene content (Salunkhe and Wu 1973). This appears to be additional to the increase which is normally associated with ripening. Curd (1988) showed that strawberries exposed to ethylene had a more intense red colour than those stored in ethylene-free air. In peas it can stimulate the formation of the toxin phytoalexin pisatin (Chalutz and Stahman 1969) and in sweetpotatoes the production of phenolics (Solomos and Biale 1975). Carrots exposed to ethylene can synthesize isocoumarin, which gives them a bitter flavour. Isocoumarin content was shown to increase with increasing concentrations of ethylene over the range of $0.5\text{--}50\ \mu\text{L L}^{-1}$ (Lafuente *et al.* 1989). Sdiri *et al.* (2012) tested degreening with $2000\ \mu\text{L L}^{-1}$ ethylene for 120 h at 21°C with 95% r.h. followed by quarantine treatment at 1°C for 16 days then shelf life at 20°C and 95% r.h. for 7 days on early-season citrus fruits. They found some changes in individual flavonoid compounds following these conditions but these changes did not contribute to a loss in the total content of flavanones and flavones. Also they did not induce detrimental changes in DPPH (1,1-diphenyl-2-picrylhydrazyl) and ferric-reducing antioxidant power, total ascorbic acid or total phenolic content.

Ripening

Changes during ripening of climacteric fruit include acids and non-structural carbohydrates. Medlicott and Thompson (1985) showed that the starch content of mangoes was completely hydrolysed to sugar during ripening. The major sugars were identified as glucose, fructose and sucrose, with the latter being

in the largest quantities. The reduction in the level of sucrose towards the end of the storage period was probably due to it being used by the fruit for metabolic activity after all the starch had been hydrolysed. In bananas ripening involves a reduction in starch content from around 15–25% to less than 5% in the ripe pulp, coupled with a rise of similar magnitude in total sugars. During the early part of ripening sucrose is the predominant sugar, but in the later stage glucose and fructose predominate.

The carotenoid content in the aril of bitter melon (*Momordica charantia*) increased during fruit ripening, lycopene being the main component, reaching $64.75\ \text{mg } 100\ \text{g}^{-1}$ fresh weight when fully ripe. Both chlorophylls a and b contents decreased significantly in the fruits stored at higher temperatures compared with those at lower temperatures (Tan *et al.* 1999). Chlorophyll content decreased during fruit development, but carotenoid content increased in bottle gourd (*Lagenaria siceraria*) (Bhatnagar and Sharma 1994).

During ripening of sapodillas at $22\text{--}28^\circ\text{C}$ and 60–70% r.h. of the cultivars Prolific and Martin grown in Venezuela, total chlorophyll, tannins, total carotenoids, TSS and fresh weight decreased and softening increased, although the postharvest patterns were different in each cultivar (Guadarrama *et al.* 2000). Wold *et al.* (2007) found that acidity, dry matter, TSS, antioxidant activity and L-ascorbic acid increased during ripening of tomatoes, but there were no significant differences in the antioxidant activity between postharvest ripened and vine-ripened fruit.

Seymour (1985) found that the carotenoid content of banana peel could change during ripening depending on temperature. Those ripened at 35.2°C had significantly increased carotenoids in the peel, while in those at 20°C carotenoids remained constant (Figure 1). The typical yellow colour of ripe bananas is developed purely because of the breakdown of chlorophyll, which masks the yellow colour in unripe bananas. At high temperature the fruit remains greenish in spite of carotenoid synthesis, because chlorophyll content is only partially reduced. These results confirm those of Von Loesecke (1950) and contradict those of Gross and Flugel (1982) who

found a decrease in carotenoids during the initial phase of ripening of bananas. Medlicott (1985) found increases in carotenoids in mangoes during ripening (Figures 2, 3, Table 4).

Packing

Almenar *et al.* (2007) described an active package that releases 2-nonanone, an antifungal volatile compound naturally present in strawberries. It was shown to delay losses of soluble solids, acidity and anthocyanin of wild strawberry fruit during storage. Storage of peas in polymethyl pentene polymeric films of 25 and 35 μm thicknesses at 5 °C modified the in-bag atmosphere to approximately 5% O_2 and 5% CO_2 . Storage in these conditions resulted in better maintenance of the pod appearance and colour, as well as chlorophyll, ascorbic acid and sugar contents compared to those stored not wrapped (Pariasca *et al.* 2001).

The cultivar Camarosa strawberry fruits were packed in 500-g capacity polypropylene punnets and wrapped automatically with 25- μm -thick polypropylene film with micro-perforations. Fruits in these packages had lower losses during storage and the degree of 'fruit ripeness and nutritional value' was said to be better preserved. However, this modified atmosphere packaging seemed to reduce fruit colour, with lower anthocyanin levels, and led to off-flavour development (Sanz *et al.* 1999). Artes-Hernandez *et al.* (2006) stored 'Superior Seedless' grapes in modified atmosphere packaging for 7 days at 0 °C then 4 days at 8 °C then 2 days at 20 °C. They found no changes in the phenolics during storage at 0 and 8 °C, but a slight decrease during the 2 days at 20 °C. Serrano *et al.* (2006) found that broccoli packed in modified atmosphere packaging film and stored for 21 days had half the loss of ascorbic acid compared to controls, which lost about one-third of its ascorbic acid on a dry weight basis. Koyuncu and Dilmaçunal (2010) stored the strawberry cultivars Dorit and Selva in perforated (eight perforations of 10 mm diameter) plastic boxes at 0 °C and 90–95% r.h. for 10 days and found that vitamin C content decreased in both.

Radiation

Cantos *et al.* (2000) showed that ultraviolet light-C radiation could increase the phenolic stilbenes, mainly resveratrol, in grapes. Perkins-Veazie *et al.* (2008) showed that there was some indication that exposure of blueberry fruit to ultraviolet light (UV-C) treatment prior to storage may increase their antioxidant levels during subsequent storage. Yan Shen *et al.* (2013) reported that exposure to UV-C increased flavonoids and total phenolics of minimally processed satsuma mandarin segments during storage and did not affect antioxidant capacity and phenolic acids. Fan and Sokorai (2008) studied the effects of irradiation at 1 kGy on iceberg, romaine, green and red lettuces, spinach, tomato, cilantro, parsley, green onion, carrot, broccoli, red cabbage and celery to control bacteria. They found that irradiation did not affect vitamin C content of most vegetables; but irradiated green and red lettuces had 24–53% lower vitamin C contents than those not irradiated. They found no other detrimental effects. Oms-Oliu *et al.* (2010) reported that pulsed light at 28 J cm^{-2} of fresh-cut mushrooms increased PPO activity, but phenolic compounds, vitamin C and antioxidant capacity were significantly reduced during 15 days of refrigerated storage.

Coating

Han *et al.* (2004) coated strawberries and raspberries with chitosan, chitosan containing 5% Gluconal[®] CAL or chitosan containing 0.2% dl- α -tocopheryl acetate and stored them at 2 °C and 88% r.h. for 3 weeks. As would be expected the coatings containing calcium or vitamin E significantly increased the content of these nutrients. Coated fruits contained 34–59 $\text{mg } 100^{-1}$ of calcium or 1.7–7.7 $\text{mg } 100^{-1}$ of Vitamin E depending on the type of fruit and the time of storage, while fruit that had not been coated contained only 19–21 $\text{mg } 100 \text{ g}^{-1}$ of calcium and 0.25–1.15 $\text{mg } 100 \text{ g}^{-1}$ of vitamin E.

1-MCP

MacLean *et al.* (2006) showed that treatment of Delicious apples with 1-MCP resulted in a significant

increase during cold storage in the total flavonoids, with the greatest increase in anthocyanins but a reduction in chlorogenic acid. Valdenegro *et al.* (2012) reported that the total antioxidant capacity was high in unripe goldenberry (*Physalis peruviana*) fruit and increased during ripening as did ascorbic

acid and polyphenol contents. Nevertheless, after harvest the antioxidant capacity was rapidly reduced during shelf life at 20 °C but treatment with 0.2 µl L⁻¹ 1-MCP significantly preserved the antioxidant capacity, vitamin C and polyphenol content.

3

Minimal processing

Minimal processing, also referred to as *fresh-cut*, refers to fruit and vegetables that have been cleaned, peeled, cut up and prepared in such a way that they are ready to eat in a convenient way. The demand for them has been steadily increasing, and there have even been international conferences dedicated solely to the subject. However, the damage inflicted in minimal processing can reduce the postharvest life compared to those that remain intact. For example Deza-Durand and Petersen (2012) demonstrated the way that lettuces were cut during the preparation could affect the amount of damage and their subsequent storage life. Another challenge is the possibility of contamination. Certain things can be done to the fruit or vegetable to ensure their safety from microbiological attack and help retain their quality. Graça *et al.* (2011) reported that sodium hypochlorite solution was the most common disinfectant used in the minimally processing industry. However, environmental and health risks related to its use have resulted in a need to find new sanitizers. In general they found that acidic electrolysed water and neutral electrolysed water were equal or more effective than sodium hypochlorite washings at 100 mg L⁻¹ of free chlorine on apple slices after storage at 4 °C for 5 days. All the washing treatments slightly decreased the levels of *Escherichia coli*, *Listeria innocua* and *Salmonella choleraesuis* that had been inoculated prior to washing. Acidic electrolysed water was the

treatment with the highest bactericidal activity. Day (1996) reported that there were highly positive effects of storing minimally processed fruit and vegetables in 70 and 80% O₂ in MA film packs. He indicated that it inhibited undesirable fermentation reactions and delayed browning (caused by damage during processing), and the O₂ levels of over 65% inhibited both aerobic and anaerobic microbial growths. The technique used involved flushing the packs with the required gas mixture before they were sealed. The O₂ level within the package would then fall progressively as storage proceeded due to the respiration of the fruit or vegetable contained in the pack.

Packaging in plastic films is almost always used to prevent them drying. An example of this technique was described by Lee and Lee (1996) who used 27 µm thick low density polyethylene film for the preservation of a mixture of carrot, cucumber, garlic and green peppers, where the steady state atmosphere at 10 °C inside the bags was 5.5–5.7% CO₂ and 2.0–2.1% O₂. Specific research has been carried out on different minimally processed fruit and vegetable and some of these are given in the following sections.

Apples

Lu and Toivonen (2000) sealed Spartan apple slices in 40-µm LDPE film bags that had a moderate

O₂ transmission rate and they remained in good condition for up to 2 weeks at 1 °C. They also investigated storage of apples before minimal processing and found that those that had been stored at 1 °C for 19 days were better in an atmosphere of 100% O₂ than the fruit that had been stored in 1% O₂. Slices prepared from fruit from 1% O₂ developed more cut surface browning, greater tissue solute leakage and enhanced accumulations of acetaldehyde, ethanol and ethyl acetate compared to that of the fruit that had been stored in 100% O₂. Al-Ati and Hotchkiss (2003) investigated altering film permselectivity (defined as the preferential permeation of certain ionic species through ion-exchange membranes) using PE ionomer films with permselectivities of 4–5 CO₂ and 0.8–1.3 O₂. The results on fresh-cut apples suggested that packaging films with CO₂ : O₂ permselectivities lower than those commercially available, which was less than 3, would further optimize O₂ and CO₂ concentration in MA packages particularly of highly respiring and minimally processed produce. Day (1996) showed that cut surface browning and flesh softening were inhibited in apple slices that had been stored in 100 or 1% O₂ compared to those that had been stored in air. However, the slices from the 100% O₂ and air contained a much lower content of fermentation products associated with off-flavours compared with the slices from apples from 1% O₂.

Aubergine

Barbagallo *et al.* (2012) found that dipping of minimally processed F₁ hybrid Birgah in 0.15 g⁻¹ calcium ascorbate was effective against degradative enzymatic activities. This treatment improved overall consumer acceptance, and they remained acceptable for up to 7 days in storage at 4 ± 0.5 °C. They found that the effect of calcium ascorbate was to inhibit PPO, PME and polygalacturonase activity, which resulted in a significant reduction of browning and softening in comparison to those not treated.

Broccoli

Bastrash *et al.* (1993) found that broccoli heads that had been cut into florets had an increased respiration

rate in response to wounding stress throughout storage at 4 °C in air, and ethylene production was also stimulated after 10 days. MA packaging can be used to extend their storage life of broccoli florets, and they also found that the atmospheres for optimal preservation was 6% CO₂ + 2% O₂ at 4 °C. This atmosphere delayed yellowing, reduced development of mould and offensive odours and resulted in better water retention during 7 weeks of storage compared to only 5 weeks in air. These effects were especially noticeable when the florets were returned from CA at 4 °C to air at 20 °C. Ansorena *et al.* (2011) found that the weight loss during storage at 5 °C for 18 days in broccoli florets coated with either chitosan or carboxy methyl cellulose was between two and five times lower compared to those not coated. Also the coated florets had better green colour retention and a reduced rate of yellowing. Chitosan coating resulted in a lower ascorbic acid loss, and the microbial load was reduced by around 1.5 logarithmic units in florets coated with chitosan and 0.9 in those coated with carboxy methyl cellulose films. Mild heat shock at 50 °C for 1½ min before storage also reduced weight loss, enzymatic browning and in delayed yellowing of broccoli florets. They concluded that a mild heat shock combined with chitosan coating was the best treatment for long-term refrigerated storage of minimally processed broccoli. Toshiya Asoda *et al.* (2009) packed broccoli florets in perforated PE bags with or without ethanol pads and then exposed them continuously to ethylene or not at 20 °C in darkness. Ethylene exposure accelerated the yellowing of florets but this was inhibited by the ethanol pads. Martínez-Hernández *et al.* (2011) tested the exposure of the broccoli florets of the cultivar Bimi[®] to UV-C doses at 1.5, 4.5, 9.0 and 15 kJ m⁻² on their quality and postharvest life. They concluded that a pre-treatment of 4.5 kJ UV-C m⁻² was useful as a technique to improve epiphytic microbial quality and health promoting bioactive compounds of minimal processed broccoli as well increasing their postharvest life during storage at 5 or 10 °C.

Controlled atmosphere storage has been evaluated on minimally processed broccoli florets. Florets of the cultivar Marathon were held for 4 days at 10 °C in containers with an air flow (20.5% O₂ and <0.5% CO₂), a restricted air flow (down to 17.2% O₂ and up to 3.7% CO₂), no flow (down to 1.3%

O₂ and up to 30% CO₂) and N₂ flow (<0.01% O₂ and <0.25% CO₂). Sensory analysis of cooked broccoli indicated a preference for the freshly harvested, and air-stored broccoli with samples stored in no flow conditions showing the opposite results (Hansen *et al.* 1993). Green Valiant heads and florets were stored at 4 °C. Minimally processing broccoli heads into florets increased the rate of respiration throughout storage at 4 °C in air, in response to wounding stress. Ethylene production was also stimulated after 10 days. Atmospheres for optimal preservation of the florets were evaluated using continuous streams of the following defined atmospheres: 0% CO₂ + 20% O₂ (air control), 6% CO₂ + 1% O₂, 6% CO₂ + 2% O₂, 6% CO₂ + 3% O₂, 3% CO₂ + 2% O₂ and 9% CO₂ + 2% O₂. The atmosphere consisting of 6% CO₂ + 2% O₂ resulted in extended storage of broccoli florets from 5 weeks in air to 7 weeks. Prolonged chlorophyll retention and reduced development of mould and offensive odours and better water retention were especially noticeable when the florets were returned from CA at 4 °C to air at 20 °C. It was concluded that minimal processing had little influence on optimal storage atmosphere, suggesting that recommendations for intact produce are useful guidelines for MA packaging of minimally processed vegetables (Bastrash *et al.* 1993).

Cabbage

In a study of minimally processed cabbages, Rinaldi *et al.* (2009) found that the reduced O₂ and increased CO₂ for 10 days did not extend the storage life at 5 or 10 °C longer than those stored in air. The atmospheres they used in a flow through system were combinations of 2–10% O₂ and 3–10% CO₂.

Carrot

SPLFS (2001) reported that storage of fresh-cut carrots was good at 0–5 °C with 2–5% O₂ + 15–50% CO₂. Lee and Lee (1996) successfully used 27-µm-thick LDPE film for the storage of a mixture of carrot, cucumber, garlic and green peppers. The steady state atmosphere at 10 °C inside the bags was 5.5–5.7% CO₂ + 2.0–2.1% O₂.

Celery

Gómez and Artés (2005) stored 15 cm long sticks of the celery cultivar Trinova in hermetically sealed plastic bags at 4 °C for 15 days. The bags were LDPE, OPP and perforated PE bags and these were compared with those stored not wrapped. Compared to those not wrapped, the sticks in LDPE or OPP had improved sensory quality, lower loss of green colour, decreased development of pithiness and retarded growth of microorganisms. Off-odours and off-flavours were not detected in any treatment. Sticks in the OPP bags retained the best quality and had a steady state atmosphere of 6% O₂ + 7% CO₂.

Cherries

A pad was made with silica gel powder containing 10 g ethanol and covered with perforated film, which allowed ethanol vapour to diffuse gradually. One pad was placed within a clamshell with 454 g of fresh-cut cherries of the cultivars Lapins and Bing. In storage at 1 °C there was about 10 µL L⁻¹ ethanol in the pack with little change within 14 days. At 10 °C there was 23 µL L⁻¹ at day 1 that decreased to 15 µL L⁻¹ by day 10. At 20 °C it was 26 µL L⁻¹ at day 1 and decreased to 13 µL L⁻¹ at day 3. A sensory taste panel did not perceive any flavour difference from the ethanol treatment. The ethanol treatment retarded softening, darkening and acid decrease in fruit as well as discolouration of the stems and extended their shelf life. Ethanol reduced brown rot (*Monilinia fructicola*) in the cherries stored at 20 °C, but not at 1 and 10 °C. A pre-packaging dip in a saprophytic yeast *Cryptococcus infirmo-miniatum* completely controlled brown rot in inoculated fresh-cut cherries stored at 1 °C and in naturally infected cherries at 20 °C (Bai *et al.* 2012).

Citrus

Del-Valle *et al.* (2009) developed a model to determine the equilibrium-modified atmosphere packaging for mandarin segments because of their high respiration rate. The model showed the need for using microperforated plastic films for the MA package. Monitoring the accumulation of fermentation volatile compounds for 3 weeks at 3 °C optimized the

number of micropores. Shen *et al.* (2013) reported that exposure to UV-C increased flavonoids and total phenolics of minimally processed Satsuma mandarin segments during storage and did not affect antioxidant capacity and phenolic acids.

Grapes

Del Nobile *et al.* (2009) found that minimally processed grapes of the cultivar Italia retained their quality during storage at 5 °C for 35 days in high barrier films. Of the films they tested a multilayer film obtained by laminating nylon and a polyolefin layer and biodegradable polyester-based films NVT-100 gave the best results.

Lettuce

Deza-Durand and Petersen (2012) demonstrate that cutting the lettuce transverse to the mid-rib caused more severe damage to the tissue than longitudinal cutting. This conclusion was based on aroma production of lipoxygenase volatiles during storage at 6 or 10 °C for up to 6 days. Day (2003) working on high O₂ storage with Iceberg lettuce packed in either 30 µm PVDC or 30 µm OPP and stored at 6–8 °C for 7–10 days found that the CO₂ content inside the PVDC film reached 30–40% which damaged the lettuce. Inside the OPP film the CO₂ level did not exceed 25%, while the O₂ level was maintained at greater than 40% and the lettuce retained their good condition. These results were confirmed by Escalona *et al.* (2006) who concluded that 80% O₂ must be used in MA packaging of fresh-cut Butter lettuce in combination with 10–20% CO₂ to reduce their respiration rate and avoid fermentation.

Papaya

For minimally processing of papaya preparation should be from fruit with 60–80% yellow surface colour since fruit with less than 55% yellow colour have a low amount of edible flesh and are difficult to de-seed, whereas fruit at full yellow colour are too soft to handle (Ergun and Huber 2004, Paull and Chen 1989, Wall *et al.* 2010). Minimally processed

papayas do not suffer chilling injury when stored at 4–5 °C, and the flesh does not turn brown from oxidation (O'Connor-Shaw *et al.* 1994, Rivera-Lopez *et al.* 2005). Microbial growth did not typically cause spoilage of fresh-cut papayas during storage at 4 °C (O'Connor-Shaw *et al.* 1994). Immersion of whole fruit in 100–200 µL⁻¹ chlorinated water prior to peeling and cutting led to low microbial counts of aerobic organisms and nearly undetectable coliforms, members of the Enterobacteriaceae and moulds (Ergun and Huber 2004, Wall *et al.* 2010). However, certain papaya cultivars have been shown to be susceptible to internal yellowing disease, caused by *Enterobacter cloacae* and *E. sakazakii* (Keith *et al.* 2008, Nishijima *et al.* 2010). The ability of *E. cloacae* and *E. sakazakii* to cause infections in humans could pose a food safety risk. The cultivars Sunrise, Sun Up and Rainbow were reported to be resistant to internal yellowing (Keith *et al.* 2008, Nishijima *et al.* 2010, Wall *et al.* 2010).

Pineapple

Budu *et al.* (2001) found that the respiration rate of peeled pineapples was very close to that of intact fruits, but their respiration rate decreased in response to slight changes in O₂ and CO₂ concentrations. They concluded that MA packaging should have important commercial applications in reducing the respiration rate and increasing the shelf life of minimally processed pineapple. For minimally processed pineapple slices Budu *et al.* (2007) found that an MA packaging giving 5% O₂ + 15% CO₂ appeared to be the most appropriate. Tancharoensukjit and Chantanawarangoon (2008) found that for fresh-cut pineapples storage in 5 or 10% O₂ + 10% CO₂ helped maintain their lightness and visual quality and prolonged their storage life for up to 9 days. Antonioli *et al.* (2007) sliced pineapples and dipped them in 20 mg sodium hypochlorite litre⁻¹ for 30 s then stored them at 5 ± 1 °C in a flow through system with different O₂ and CO₂ concentrations. None of the atmospheres seemed to give an advantage since the slices stored in air had little browning and were free of contamination that would affect the food safety at the end of the storage period. Antonioli *et al.* (2006) did not detect ethylene production during the initial period of 12 h after minimal processing and storage

at 5 °C. They also found that the initial respiration rate of pineapple slices and chunks was double that observed in the peeled fruits. The respiration rate of slices and chunks was very similar during 14 days of storage.

Mango

Tovar *et al.* (2001a, 2001b) compared storage of Kent mango slices with whole fruit at 23 °C and 65% r.h. TSS of slices did not show the same trend as whole fruits and remained unchanged at their initial values but there was some loss of yellow pigments and browning. TA increased in the slices and was different from the whole fruit. Decay occurred between days 5 and 7 of storage in slices, but when slices were stored at 13 °C there was minimal changes owing to cutting.

Dea *et al.* (2010b) reported that for the best visual quality retention of minimally processed fruits, the preferred storage temperature is never higher than 5 °C, which is considered a chilling temperature for chilling-sensitive tropical fruit such as mango. However, they found no evidence of chilling injury during storage of Kent for 10 days. On minimally processed, partially ripe Kent mangoes Dea *et al.* (2010b) found that visual quality degradation was faster at 12 °C than at 5 °C and limited the shelf life of the minimally processed mangoes to 3–4 days at 12 °C compared to 5–6 days at 5 °C. TSS content did not differ between whole fruit or fresh-cut slices stored at either 12 or 5 °C, but respiration rate and total ascorbic acid were all lower and TA was higher in both the fresh-cut slices and whole fruit stored at 5 °C compared with those stored at 12 °C.

Djioua *et al.* (2009) dipped whole Keitt mangoes in hot water at 46 or 50 °C for 30 or 75 min, cooled them for 15 min, minimally processed them before storage at 6 °C for 9 days. They found that hot water dipping at 50 °C for 30 min was the only one to maintain the acceptability of minimally processed mangoes for 6 days. This treatment also improved the retention of the yellow colour, their firmness and increased the retention of total carotenoids. Although the ascorbic acid content decreased during storage, it was lowest in this treatment, as was lipid peroxidation. They concluded that hot water dipping at 50 °C for 30 min was the optimal heat treatment to improve the quality of minimally processed Keitt mangoes. Robles-Sánchez

et al. (2009) studied the influence of dipping fresh-cut Kent mango cubes in ascorbic acid, citric acid and calcium chloride solution during storage at 5 °C. They found that, in general, addition of ascorbic acid as an anti-browning agent not only retarded quality loss of fresh-cut mango cubes but also promoted significant increases in antioxidant activity in comparison with control samples. The treated mangoes showed better colour retention than non-treated mangoes during storage and had significantly increased levels of vitamin C. However, β -carotene was not affected by dipping treatments and vitamin E showed a significant decline over during storage for both treated and non-treated mango cubes, but higher vitamin E values were found in treated mangoes. Dea *et al.* (2010a) suggest that the hot water quarantine treatment applied to whole mangoes imported into the United States did not significantly affect the quality of fresh-cut Kent mango slices made from them and stored at 5 °C. The visual quality, electrolyte leakage, firmness and aroma volatile production (based on the quantification of 16 aroma volatiles) did not differ between the fresh-cut slices prepared from hot-water- and non-hot-water-treated fruit.

Plotto *et al.* (2006) exposed whole mango fruit to various treatments before they were sliced then stored the slices in plastic clam shells for 15 days at 7 °C. They found that slices that had been submerged in hot water at 46 °C for 60 or 90 min then stored at 20–25 °C for 4 days and exposed to ethanol vapours for 20 h maintained higher fruit firmness, hue angle and TA in storage. However, internal ethanol and acetaldehyde were very high in slices from fruit that had been exposed to ethanol vapours for 20 h. They concluded that, owing to inconsistent results, ethanol vapour applied for 20 h to whole mangoes prior to processing for fresh-cut fruit was not a practical approach to delay ripening. However, 10-h exposure could be used as a safe microbial control in a minimally processed production sanitation system. Beaulieu and Lea (2003) reported that subjective appraisals of minimally processed Keitt and Palmer mangoes, based on aroma and cut edge or tissue damage, indicated that most of the cubes prepared from soft-ripe fruit were unmarketable after 7 days of storage at 4 °C in clamshells. They found that the CO₂ and O₂ levels inside the MAP clamshell were inadequate to prevent potential anaerobic respiration during 7 days of storage. The combination of

calcium and CA storage were applied to minimally processed mangoes. de Souza *et al.* (2006) found that the symptoms limiting shelf life in the cultivar Kensington were tissue darkening, development of a glassy appearance, surface desiccation and loss of firmness. Reducing the O₂ levels around the slices to 2.5% was effective at controlling tissue darkening and the development of a glassy appearance. Treating the slices with 3% calcium chloride significantly slowed, but did not stop, loss of tissue firmness and partly effective at controlling darkening. They concluded that a combination of pre-treatment with calcium and low O₂ storage allowed Kensington slices to be kept for at least 15 days at 3 °C.

Melon

The effect of chitosan/methyl cellulose films on microbial characteristics of minimally processed cantaloupe and pineapple was examined. Chitosan/methyl cellulose and vanillin films provided an inhibitory effect against *E. coli* and *S. cerevisiae*. The functional properties of chitosan-based films can be improved by combining them with other hydrocolloids and film-forming materials (Tamer and Çopur 2010).

Mushrooms

When mushrooms are minimally processed into slices they have a shortened postharvest life and therefore need a special care to retain their freshness (Iqbal *et al.* 2009). They also observed that mushrooms sliced to 8 mm thick had a respiration rate increase of 30% at 0 °C and 40% at 20 °C compared to whole mushrooms. Minimally processed mushrooms are usually marketed in trays overwrapped with perforated PVC stretchable film (Simon *et al.* 2005). Application of 1% chitosan coating on minimally processed mushrooms delayed discolouration associated with reduced activities of polyphenoloxidase, peroxidase, catalase, phenylalanine ammonia lyase and laccase, as well as lower total phenolic content and reduced activities of cellulase, total amylase and α -amylase. Microbiological development of the samples treated with chitosan coating was also

inhibited compared to the control (Tamer and Çopur 2010). Koorapati *et al.* (2004) evaluated the effect of electron-beam irradiation on quality of white button mushroom and observed that irradiation levels above 0.5 kGy prevented microbial-induced browning. They recommended that irradiation at 1 kGy was the most effective in extending the shelf life of mushroom slices.

Strawberry

Strawberries were treated with a solution of 1% chitosan, packaged in MA packages with either 80 or 5% O₂ and then stored at 4, 8, 12 and 15 °C. The coating inhibited the growth of microorganisms at all temperatures especially combined with high O₂, which also seemed to help to retain their colour (Tamer and Çopur 2010).

Spinach

Medina *et al.* (2012) showed that controlled humidity after harvest was critical as it can influence the microbiological population and the maintenance of acceptable visual quality of minimally processed baby spinach. At 99% r.h. spinach had a higher respiration rate, higher percentage of leaf damage, increased electrolyte leakage and a shelf life of 4 days shorter than spinach exposed to 72 or 85% r.h. The observed changes were mainly linked to a significant postharvest breakage, which influenced the susceptibility to microbial colonization. Psychrophilic bacteria and *Pseudomonas* counts of samples exposed to high humidity were 1 log higher than those exposed to low and medium humidity. Baby spinach exposed to low humidity conditions on the one hand significantly showed lower water content and higher osmotic potential and stiffness after exposure for 36 h at 15 °C when compared to high humidity conditions. After processing, samples exposed to low humidity were rehydrated and no differences in dehydration were observed among samples exposed to different humidity conditions. They recommended that to minimize the impact of leaf damage, baby spinach should be processed at medium to low hydration levels.

Watermelon

Artés-Hernández *et al.* (2010) investigated the use of UV-C illumination at 0, 1.6, 2.8, 4.8 and 7.2 kJ m^{-2} on storage of watermelon cubes in modified atmosphere packages. The gas content for all doses reached an equilibrium of 3–6% O_2 and 13–17% CO_2 . All the UV-C-treated fruit had lower microbial counts just after illumination and also after 11 days of

storage at 5°C . The mesophilic, psychophilic and enterobacterial populations were significantly lower in UV-C-treated watermelon cubes. The optimum UV-C illumination was 0, 1.6 and 2.8 kJ m^{-2} in terms of sensory quality, and they could be stored for up to 11 days at 5°C . At higher UV-C exposure fruit could be stored for only 8 days at 5°C .

4

Specific recommendations for vegetables

Abyssinian yam

Dioscoreaceae

Dioscorea abyssinica Hochst. is native to Ethiopia and cultivated to a limited extent in other eastern Africa countries especially Uganda and from Mali to northern Nigeria (Burkill 1951, Coursey 1967). A non-spiny climber grows up to 4 m high; it is possibly an ancestor of *D. cayenensis*. The tuber is edible and palatable, but grows deep into the ground and therefore it is difficult to harvest.

Ackee

Sapindaceae

Bligha sapida Koenig, also called akee. It is a native of forests of West Africa and was introduced to Jamaica in the late 18th century where it forms part of the national dish of salt fish and ackee. The genus is named after William Bligh the commander of the ship HMS Bounty famed for its mutiny when transporting breadfruit from Tahiti to the West Indies in 1789.

It is a polygamous tree grows up to 25 m tall. The fruit is a capsule and is bright red in colour. It is ovoid in shape, about 6 cm long and 3 cm in diameter and contains three shiny black seeds attached to the aril by a pink or purplish membrane called the raphe. The raphe is the line of

fusion between the funicle and the integument of the ovule. The edible portion is the aril that is white turning a creamy colour as the fruit matures (Figures 4 and 5). Purseglove (1972) reported that they can be eaten raw but are more commonly cooked and its yellow colour resembles scrambled egg in both appearance and taste. Hypoglycin (L-2-amino-3-[methylenecyclopropyl]-propionic acid) is the water-soluble toxic ingredient of the unripe fruit and to a much lesser extent in ripe fruit. It is referred to as *hypoglycin A*. Hypoglycin B is also found in fruits but is less toxic. The raphe contains high levels of hypoglycin and should be carefully removed in preparation for eating. Emanuel and Benkeblia (2011) hypothesized that, as the fruit matures hypoglycin A is translocated from the arils to the seed where it is converted into hypoglycin B. They also reported that cooking ripe ackees leaches hypoglycin A and therefore effectively eliminates toxicity, while in unripe ackees the toxins are not destroyed during cooking. They also cite several studies in Jamaica including that between 1880 and 1955 when 151 cases and 32 deaths were associated with consumption of ackee. A case study involving a 27-year-old Jamaican man was reported by Larson *et al.* (1994). The man developed jaundice, pruritus, intermittent diarrhoea and abdominal pain following chronic ingestion of canned ackee fruits. Liver function tests returned to normal and his symptoms were completely resolved when he stopped eating the fruit.



Figure 4 Ackee fruit ready for harvesting where the fruit has split and the seeds are exposed. See colour plate section.



Figure 5 Ackee fruit showing the edible aril.

The fruit is green as it develops on the tree, then turns yellow and then red as it matures. When the fruit is fully mature on the tree it splits open along three sutures revealing its three black seeds on yellow arils. It should be harvested when fully mature otherwise it may be toxic (Figure 4). Information on its postharvest life could not be found in the literature. As indicated earlier they should be harvested when the fruit is fully red and it splits along the three sutures. However, companies who process the fruit in Jamaica have been seen to lay the fully red fruit on wire trays, to allow for good air circulation, in ambient temperatures of about 28–30 °C. The fruit eventually split and then they are canned. Any fruit that do not split are said to be rejected but even so this practice is potentially dangerous.

Adzuki beans

Fabaceae, Leguminosae

Vigna angularis (Willd.) Ohwi & Ohashi synonymous with *P. angularis* (Willd.) Wight. Carbonized azuki bean seeds have been found from archaeological sites in Japan dated about 4000 years ago predating remains in China and Korea. This means that Japan is one possible place where azuki bean was domesticated (Yano *et al.* 2004). Xu *et al.* (2008) reported that cultivated azuki beans from China, Korea and Japan were the most diverse and were genetically distinct from each other, suggesting a long and relatively isolated history of cultivation in each country. Cultivated azuki beans from eastern Nepal and Bhutan were similar to each other and quite distinct from those from China, Korea and Japan. They are grown primarily in East Asia and are the second most important legume in Japan after soya bean, but they have been introduced into the southern United States and Hawai'i.

It is an erect bushy annual herb grows up to 75 cm high that produces bright yellow flowers and thin-skinned pods up to about 10 cm long containing up to 10 seeds. They are commonly straw or black to brown coloured when mature. Some 80% of pods mature at the same time so they can be harvested in a single operation and it is important to harvest promptly as shattering can result in losses.

African breadfruit

Moraceae

Treculia africana Decne. ex Trecul. It is the only species in the genus *Treculia* and is also called ukwa, African boxwood, okwabaum, arbre à pain d'Afrique, wild jackfruit and saquiente. In spite of its common name it is believed to be native to the area extending from New Guinea through the Indo-Malayan archipelago to western Micronesia. It is largely cultivated within the rainforest belt of West, Central and East Africa as well as Madagascar.

In Nigeria the seed is used for preparing pudding, as a thickener soups or in porridge alone or mixed with cereals such as sorghum or roasted and sold with palm kernel (*Elaeis guineensis*) as a roadside snack. The seeds are highly nutritious and it is an important natural resource for the poor, contributing significantly to their income and dietary intake. It is also

used as an animal feed (Onweluzo and Nnamuchi 2009). The leaf decoctions were reported to be used in Trinidad and Tobago and the Bahamas to lower blood pressure (Morton 1987), and it is used also in some communities as an effective treatment for stomach upset and other gastrointestinal infections. The aqueous ethanol extract of the bark was effective in an *in vitro* study on gastrointestinal bacterial pathogens (Ogbonnia *et al.* 2008a and Ogbonnia *et al.* 2008b). The seed is also used in the traditional medicine.

It is an evergreen forest fruit tree that produces large, usually round, compound fruits covered with rough pointed outgrowths. The fruit is some 45 cm in diameter and they contain edible seeds embedded in spongy pulp. They are boiled, roasted or made into flour (Purseglove 1968). The fruits are hard and fibrous and weigh up to 8.5 kg. It should not be confused with the breadfruit *Artocarpus altilis*, which belongs to the same family.

Osabor *et al.* (2009) reported that the seed contained 8% moisture, 73% carbohydrate, 12.5% crude protein, 4.2% fat, 2.3% ash and 1.6% fibre on a dry mass basis. They also contain 0.06 ± 0.12 mg 100 g^{-1} hydrocyanide, 3.0 ± 0.11 mg 100 g^{-1} oxalate and 0.76 ± 0.01 mg 100 g^{-1} of phytate that are toxins as well as appreciable amounts of flavonoid, polyphenols, anthraquinones, saponins and cardiac glycosides. Proximate analysis by Akubor *et al.* (2000) gave the composition of the seeds as 17–23% crude protein, 11% crude fat and other essential vitamins and minerals.

Nwaiwu *et al.* (1995) reported that storage at 5°C reduced spoilage from 100 to 0% compared to storage in Nigerian ambient conditions. Immersion in 15% sodium chloride solution before storage reduced spoilage during subsequent storage from 100 to 5%. They also reported that the microorganisms associated with biodeterioration were 72% fungi (*Aspergillus niger*, *Rhizopus stolonifer* and *Botryodiplodia theobromae*) and 28% bacteria (*Erwinia* spp.). No bacteria were isolated from seeds only from the pods.

African yam bean

Fabaceae, Leguminosae

Sphenostylis stenocarpa (Hochst. ex A. Rich.) Harms. It is synonymous with *S. ornata* A. Chev. Other

common names include yam bean, wild yam bean and yam pea. Jicama (*Pachyrhizus erosus* (L.) Urban) is also called yam bean. Edem *et al.* (1990) referred to its origin as being West Africa where it is commonly cultivated. It is one of the most important tuberous legumes of tropical Africa and is usually cultivated as a secondary crop with yam in Ghana and Nigeria. In West Africa the seeds are preferred to the tubers but in East and Central Africa the tubers are a very important food source.

Coursey and Booth (1977) described it as a trailing vine commonly grown on mounds similar to yams. Its fleshy roots are 'turnip-like' and its pods can be eaten as a vegetable. Moisture content of the freshly harvested seeds varied from 2.84 to 3.13% and on a dry matter basis it was 2.93–3.23%. The seed is highly priced, very rich in protein and other nutrients and it is generally consumed throughout South Eastern Nigeria and other parts (Asoiro and Ani 2011). The USDA Nutrient Database (2012a) gave an analysis for the composition of podded beans (Table 5). It is an annual crop; its pods are green as they mature and are harvested when they are just beginning to change to brown signifying the onset of drying (Asoiro and Ani 2011).

Table 5 Chemical content of the pods of African yam bean (*Sphenostylis stenocarpa*) in 100 g^{-1} fresh weight (source: adapted from USDA 2012a)

Water	88.89 g	Thiamine	0.150 mg
Energy	42 kcal	Riboflavin	0.080 mg
Protein	2.80 g	Niacin	0.600 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.160 mg
Carbohydrate, by difference	7.55 g	Folate	42 μg _DFE
Total dietary fibre	2.6 g	Vitamin B-12	0.00 μg
Sugars, total	4.00 g	Vitamin A	54 μg _RAE
Calcium	43 mg	Vitamin A	1087 IU
Iron	2.08 mg	Vitamin E	0.39 mg
		(α -tocopherol)	
Magnesium	24 mg	Vitamin D (D2 + D3)	0.0 μg
Phosphorus	53 mg	Vitamin D	0 IU
Potassium	200 mg	Vitamin K	25.0 μg
		(phyloquinone)	
Sodium	4 mg	Fatty acids, total saturated	0.039 g
Zinc	0.27 mg	Fatty acids, total monounsaturated	0.021 g
Total ascorbic acid	60.0 mg	Fatty acids, total polyunsaturated	0.089 g

Amaranth

Amaranthaceae

Amaranthus spp. Some species of *Amaranthus* are grown for their grains including *A. caudatus* L., *A. cruentus* L., *A. hypochondriacus* L. and *A. leucocarpus* S. Wats. It originated in Central and South Americas where they have been important as a food since 5000–3000 BCE. *A. leucocarpus* was important to the Aztecs in Mexico and the emperor Montezuma was said to receive an annual tribute of 200,000 bushels of Amaranth seed (Purseglove 1972).

Amaranthus spp. are herbaceous annuals that are grown as a leafy vegetable as well as a grain legume. For the leaves they are harvested when individual leaves are still young and tender while the pods are allowed to dry out and the whole plant is harvested and the seeds removed. Refrigerated storage recommendations for the leaves include 0 °C and 95–100% r.h. for 10–14 days (SeaLand 1991) and 0–2 °C and 90–98% r.h. Onyango (2010) reported that in Nairobi the demand for vegetable amaranth (*A. hypochondriacus*) was high but there were problems of a short shelf life. However, she found that during storage at 4 °C for up to 4 days, the ascorbic acid, β -carotene and total phenolics were maintained. Various other methods of preservation have been described. Sun-dried amaranth leaves resulted in reductions in the levels of ascorbic acid and β -carotene of 87.4 and 16.3%, respectively. After storage of the dried leaves for 3 months, the retention of ascorbic acid was 42 mg 100 g⁻¹ at 22 °C, 40 mg 100 g⁻¹ at 28 °C and 36 mg 100 g⁻¹ at room temperature of 30–32 °C and β -carotene were 32.4 mg 100 g⁻¹ at 22 °C, 29.5 mg 100 g⁻¹ at 28 °C and 27.4 mg 100 g⁻¹ at room temperature on a dry matter basis (Mziray *et al.* 2000).

Anise

Umbelliferae

Pimpinella anisum L. also called anis. It is of Mediterranean origin where it was used by ancient Egyptians, Greeks, Hebrews and Romans. It is now cultivated in Europe, Asia Minor, India, Colombia and Mexico but it does not grow satisfactorily in the lowland tropics (Purseglove 1972). It was valued in the Middle Ages as a medical plant. It contains 1.5–5% of the

essential oil aniasol that may be extracted and used as a perfume or medicine as a carminative and for the relief of gastrointestinal spasms. It is also used in flavouring curries, sweets, confectionery and liquors such as aguardiente in Colombia (Purseglove 1972). The edible portion is the leaf petiole, which can be used in salads.

It is a pubescent annual herb that grows up to 60 cm high with yellow or white flowers and ovate ribbed seeds that are small and green to yellow in colour (Purseglove 1972). Refrigerated storage recommendations include 0 °C and 90–95% r.h. for 14–21 days (SeaLand 1991) and 0–2 °C and 90–98% r.h. (Thompson 1996). The use of 60% CO₂ to disinfest anise in a 5-day exposure in a 4 m³ stainless steel fumatorium and 30 m³ fumigation chamber under temperatures ranging between 28 and 35 °C resulted in complete control of pupal and adult stages of *Stegobium paniceum* and *Lasioderma serricorne* (Hashem 2000).

Añus

Tropaeolaceae

Tropaeolum tuberosum Ruiz and Pav. Other common names include cubios, mashua, ysaño and tuberous nasturtium. It is a native to the high Andes, and it remains confined to this area where it is cultivated in valleys of Peru and Bolivia normally at altitudes of 3000 m or above (Kay 1987).

It is a perennial climber that produces conical or ellipsoidal tubers that are up to 15 cm long and 6 cm in diameter. Tubers are usually greyish-white with the furrows tinged purple, but can be yellow or greenish with purple markings. The stems are green or reddish-green and the leaves show variation in form and are up to 20 cm long, peltate, with 3–5 lobes. The flowers have orange petals with a red calyx that forms a spur, sometimes two (Kay 1987).

Kay (1987) reported the following composition for tubers: energy 218 kJ 100 g⁻¹, water 86%, carbohydrate 11%, protein 1.6%, fat 0.6%, fibre 0.8%, ash 7%, calcium 7 mg 100 g⁻¹, iron 1.2 mg 100 g⁻¹, phosphorus 42 mg 100 g⁻¹, vitamin A 0.015 mg 100 g⁻¹, thiamine 0.06 mg 100 g⁻¹, riboflavin 0.08 mg 100 g⁻¹, niacin 0.6 mg 100 g⁻¹ and ascorbic acid 67 mg 100 g⁻¹. In a study of four Andean root crops, Campos *et al.* (2006) found that the content of bioactive

compounds was high and variable between crops and within the genotypes studied. The antioxidant capacity within the four crops studied varied from 483 to 9800 μg trolox equiv. g^{-1} . Phenolics ranged from 0.41 to 3.37 mg chlorogenic acid equiv. g^{-1} , anthocyanins ranged from 0.08 to 2.05 mg cyanidin 3-glucoside g^{-1} and carotenoids ranged from 1 to 25 μg β -carotene g^{-1} . In general, *T. tuberosum* tubers showed the highest antioxidant capacity and phenolic, anthocyanin and carotenoid content compared with native potato, oca and ulluco. The overall average moisture content of the 11 genotypes studied, which had been supplied by the International Potato Center, was $89 \pm 2.2\%$. A protein difference of 120% was observed among *T. tuberosum* cultivars and a protein difference of 300% was observed among the three species of *T. tuberosum*, *Ullucus tuberosus* and *Oxalis tuberosa* (King and Gershoff 1987). Harvesting is usually some 7 months after planting, and it is carried out by digging them by hand. Tubers have a storage life of up to 6 months at ambient temperatures (Kay 1987).

Apios

Fabiaceae

Apios americana Medikus and *A. princena*. Other common names include cinnamon vine, potato bean, hopniss, Indian potato and groundnut (not to be confused with the groundnut or peanut *Archis hypogaea* L.). It originated in North America and was an important food plant in pre-Colombian times. When European explorers first visited the Americas they found the natives eating the seeds and tubers of apios. Despite its wide use, most Indians gathered apios from the wild and, although some tribes transplanted them near their campsites, it probably was never cultivated (Beardsley 1939, quoted by Reynolds *et al.* 1990). Apios may have been taken to Europe by 1597 and was evaluated in 1845 as a potential crop to replace or supplement potato (*Solanum tuberosum*) production during the potato famine in Ireland (Seabrook and Dionne 1976, Reynolds *et al.* 1990). Tubers are high in protein and carbohydrates (Walter *et al.* 1986) and are preferred by some to *Solanum tuberosum*. Its potential as a new crop was described by Reynolds *et al.* (1990).

It is an herbaceous perennial that grows up to 3–4 m long, with pinnate leaves 8–15 cm long with 5–7 leaflets with red-brown to purple flowers, produced in racemes. The fruit is a legume up to 12 cm long. The tubers are nutritious, with a high content of starch and protein. It is unusual among root and tuber crops in that it fixes nitrogen. They are commonly propagated by seed but tubers can also be used. There appeared to be variability of nutritional components among different lines (Reynolds *et al.* 1990). They reported that the crude protein was 25–30% for seeds and 11–14% for tubers on a dry defatted basis. Aspartic and glutamic acids were the predominant amino acids in both seeds and tubers. The relative balance of essential amino acids was found to be excellent except for cysteine and methionine, which are usually low in legumes. Seeds contained 12–18% and tubers approximately 4% lipid on a dry weight basis. Fatty acid profiles of seeds and tubers differed but, linoleic acid predominated.

Arracacha

Umbelliferae

Arracacia xanthorrhiza Bancroft synonymous with *A. esculenta* DC. Other common names include Peruvian parsnip, lakachu, lekachu, oqqe, huiasampilla, laqachu, raqacha, virraca, rikacha, racacha, zanahoria blanca, apio criollo, sonarca, batata baroa, mandioquinha, batata salsa, batata cenoura, panème and pomme de terre-céleri. This is possibly one of the oldest cultivated Andean plants, its domestication having preceded that of the potato (*Solanum tuberosum*). It is a native of the Andes region of South America and is usually cultivated at altitudes between 1500 and 2000 m. It is not possible to identify its exact area of origin, although it could have been the northern part of South America, in view of the presence there of related wild *Arracacia* species. They are a staple root crop in parts of South and Central Americas particularly Colombia, Ecuador and Peru but cultivation has now spread to the Antilles, Venezuela, Africa, Sri Lanka and in large commercial areas in southern Brazil, where it has been industrialized (Higueta 1964, Kay 1987). They are eaten boiled or as an ingredient in soups and stews and as a puree, roasted and fried in slices. The leaves are prepared in the same way as celery in raw or cooked salads, hence the Venezuelan

name apio criollo which is Spanish for creole celery and the French pomme de terre-céleri.

The plant is a perennial herb grows up to 1 m high with deeply divided leaves and loose umbels of small flowers (Purseglove 1972). It produces spindle-shaped smooth-skinned fleshy tuberous roots, several of which are borne as lateral projections from the central rootstock. They are light brown in colour with white flesh and are usually small, but can weigh up to 3 kg (Kay 1987). Popenoe (1992) stated that 'it produces a carrot-like root with a delicate flavour of cabbage, celery and roasted chestnuts and can be boiled, fried or added to stews'. Two kinds of roots emerge from the stem: long and fine ones or tuberous and fusiform ones. The latter are the ones that are used. They are 5–25 cm long and up to 8 cm in diameter.

Analyses of the lateral swollen roots of arracacha from Colombia showed that they had water 71.9–73%, carbohydrate 24.9%, protein 0.8–1.1%, fat 0.1–0.2%, fibre 0.6–0.8%, ash 1.6%, calcium 24 mg 100 g⁻¹, iron 0.7 mg 100 g⁻¹, phosphorus 65 mg 100 g⁻¹, vitamin A 20–60 IU 100 g⁻¹ (in yellow cultivars), thiamine 0.04–0.06 mg 100 g⁻¹, riboflavin 0.03–0.04 mg 100 g⁻¹, niacin 2.7–3.4 mg 100 g⁻¹ and ascorbic acid 15–28 mg 100 g⁻¹. The starch content ranged between 10 and 25% (Kay 1987). After 2–3 months of storage, the sugar content in the roots increased through breakdown of starch.

Harvesting and handling

The roots are harvested some 4 months after planting, depending on the cultivar and region. Souza *et al.* (2003) identified four main types of postharvest mechanical damage in arracacha roots in Brazil, which were abrasion, partial rupture, splitting and breakage. Abrasion was the most common damage reaching 13.3% of the roots at the farm, 19.7% before washing and 24.9% after washing at the packhouse, 47.2% at the wholesale market and 78.9% at the retail market. The incidence of other types of mechanical damage was 7.6% rupture, 4.2% splitting and 10.6% broken roots at the wholesale market. The critical point for the incidence of mechanical damage in the postharvest chain occurred between the packhouse and the wholesale market probably because of inadequate packing in wooden boxes and rough handling.

Henz *et al.* (2005) carried out experiments dropping arracacha roots 90 cm onto a hard surface and found that their respiration rates during storage at 24 °C were 15.3 ml CO₂ kg⁻¹ h⁻¹ for roots not dropped and 34.4 ml CO₂ kg⁻¹ h⁻¹ for those that had been dropped. Injured roots stored at 24 °C had 84% deteriorated after 4 days, while those stored at 5 °C had no deterioration.

Storage

At room temperature in Bogotá (about 25 °C and 40% r.h.) they turned black in 3 days (Amezquita Garcia 1973). Scalon *et al.* (2002) found that roots stored without packaging were unfit for marketing after 21 days. Ribeiro *et al.* (2005) reported that chilling injury occurred in storage at 5 °C. The symptoms of chilling injury were the development of irregular pit lesions in the whole surface, followed by intense internal discolouration. Refrigerated storage recommendations were:

- 3 °C for 1 month (Kay 1987).
- 10 °C and 90% r.h. for 1 month with a small weight loss and slight fungal infection (Amezquita Garcia 1973).
- 10 °C and 90% r.h. (Lutz and Hardenburg 1968).
- 25 °C and 40% r.h. for less than 4 days (Thompson 1981).

Modified atmosphere packaging

The ambient conditions for packaging roots in Bogotá were 17–20 °C and 68–70% r.h. Thompson (1981) found that roots deteriorated much quicker but could be stored for 7 days if wrapped in plastic cling film or plastic shrink film. Scalon *et al.* (2002) also found that roots stored in PVC film had lower weight losses than those in cellophane film, but those in cellophane film had a better marketing appearance.

Transport

Burton (1970) studies shipments of roots from Puerto Rico to Chicago at 13.5 °C taking 9 days. On arrival most were in poor condition, but the sound roots were stored for a further 30 days at 15 °C and 65% r.h. After this time their weight loss over the 30 days was 15 and 12% had decayed. Treatment before storage with 2500 µl L⁻¹ chlorine plus wax reduced these losses to 1 and 6%, respectively.

Diseases

The causes of postharvest losses were mainly fungal and bacterial rots and desiccation, which led to high market wastage. Washing roots increased rotting and the addition of chlorine to the washing water was ineffective. Dipping roots after harvest in benomyl, with or without maneb, reduced but did not eradicate rotting. Individual wrapping of roots in plastic cling or shrink films reduced rotting and desiccation (Thompson 1981). Benomyl use is not permitted in many countries.

Arrowhead

Aponogetonaceae, Alismataceae

Sagittaria sagittifolia L. also called swamp potato and swan potato. Also Chinese arrowhead *Sagittaria trifolia* var. *edulis*. It is believed to be a native of the more temperate parts of China and is found growing wild or in a semi-wild state in the marshes and lakes of China, Japan, India, Malaysia, the Philippines and some Pacific islands. It has now spread to tropical and subtropical parts of Asia. A closely related species, *S. latifolia* Willd., is native to North America, and there may be some confusion between the species in the literature. The corms are used as a starchy vegetable after boiling and are a constituent of several Japanese and Chinese meat dishes. The tubers are sometimes used as a source of starch or for animal feed. The young leaves can be eaten as a green vegetable and are also used for medicinal purposes in China.

It is a perennial, robust, aquatic plant grows up to 1.2 m tall, with smooth, broad sagittate leaves, raised above the water level. The inflorescence is erect, long-peduncled, glabrous, racemose, simple or branched with white flowers sometimes with a purple-spotted base. Small subterranean tuberous rhizomes, also called corms, are produced at the base of the erect stem. They are covered with whitish or bluish-white scales, have a globular base and an acute apex and are about 5 cm in diameter weighing up to about 30 g. The corms mature in about 6–7 months and are dug by hand.

The composition of the edible portion of the corms was reported by Kay (1987) as: energy 448 kJ 100 g⁻¹, water 70.6%, carbohydrate 22.4%, protein 5%, fat 0.3%, fibre 0.9%, calcium 13 mg 100 g⁻¹, iron

2.6 mg 100 g⁻¹, phosphorus 165 mg 100 g⁻¹, potassium 729 mg 100 g⁻¹, thiamine 0.16 mg 100 g⁻¹, riboflavin 0.04 mg 100 g⁻¹, niacin 1.4 mg 100 g⁻¹ and ascorbic acid 5 mg 100 g⁻¹. The carbohydrate consisted mainly of starch with about 2% of sucrose. Sagittariol, an anti-inflammatory principle, has also been found in the corms. In Hawai'i USDA (2011a) prohibited movement of *S. sagittifolia* unless the importer has a valid PPQ Form 526 Permit. This noxious weed is prohibited by 7CFR 360-Noxious Weed Regulations.

Arrowroot

Marantaceae

Maranta arundinacea L. Other common names include West Indian arrowroot, Bermuda arrowroot, araru and ararao. The genus *Maranta* includes 20 species of perennial herbs. The plant produces large fleshy cylindrical subterranean rhizomes which are up to 2½ cm in diameter and up to 25 cm long, which are covered in overlapping scale leaves (Kay 1987). *M. arundinacea* should not be confused with Queensland arrowroot (*Canna edulis*), Brazilian arrowroot (*Manihot esculenta*), Indian arrowroot (*Curcuma angustifolia*), Mexican arrowroot (*Dion edule*), Chinese arrowroot (*Nelumbium speciosum*) and Portland arrowroot (*Arum maculatum*) (Shen-Miller *et al.* 2002).

It is believed to have originated in the north western part of South America and the Lesser Antilles. There is evidence of arrowroot cultivation 7000 years ago as the food and medicine of the Carib and Garifuna peoples. St. Vincent has a long history of arrowroot production, which arose from humble beginnings to the status of a major export during the period 1900–1965. Fields of arrowroot can still be seen in St. Vincent but it is grown on a much smaller scale. Ruins remain of the various 19th century factories used for processing arrowroot starch on St. Vincent. It has also been widely distributed throughout tropical countries including India, Sri Lanka, Indonesia, the Philippines and Australia. In India, it is grown in Uttar Pradesh, Bihar, Orissa, West Bengal, Assam and Kerala. (Edison *et al.* 2006). Napoleon supposedly said the reason for the British love of arrowroot was to support their colonies. Cultivation of arrowroot was developed to partly replace

the declining sugar industry but since the 1950s, bananas have replaced arrowroot as St. Vincent's major export. The name may come from the Arawak word *aru-aru* that means meal of meals but it has also been suggested that the name came from the use of arrowroot in treating poison arrow wounds, as it draws out the poison when applied to the site of the injury (Handler 1971). He also pointed out that 'the Carib primarily employed the plant in poultices for sores and wounds, including those caused by poison arrows'. Another species, *M. malaccensis*, has poisonous roots used as an ingredient in a Borneo arrow-poison.

The rhizomes can be eaten after boiling or roasting. Production of arrowroot starch is by extraction from rhizomes that are not more than a year old. Rhizomes are washed, pulped in wooded mortars, stirred in water and wrung out by hand. The milky liquor is sieved, allowed to settle and then drained. After cleaning and draining the extract is dried on sheets in the sun. The starch yield is about one-fifth of the fresh weight of the rhizomes.

Arrowroot starch is easily digested and therefore in demand for infants and invalids. Typical analyses of the rhizomes of the cultivar Creole showed that they had water 69.1%, protein 1%, fat 0.1%, starch 21.7%, fibre 1.3% and ash 1.4%. For the rhizomes of the cultivar Banana the composition were water 72%, protein 2.2%, fat 0.1%, starch 19.4%, fibre 0.6% and ash 1.3% (Kay 1987). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 6.

Harvest maturity is some 10–12 months after planting when the leaves begin to wilt and die down and the stems lodge (Purseglove 1972). In St. Vincent harvesting is usually by hand, which involves breaking off the rhizome from the shoot. Modified potato harvesters have been used in both St. Vincent and Australia. The cultivar Banana, which has shorter, thicker, less fibrous rhizomes, produced near the soil surface is more easily adapted to mechanical harvesting (Kay 1987).

Storage is usually achieved by delaying the harvest, but the rhizomes may become fibrous and some of the starch is eventually converted into sugar when they sprout (Purseglove 1972). There is little information on storage life except that they deteriorate rapidly after harvest, the cultivar Banana must be processed

Table 6 Chemical content of arrowroot rhizomes (*Maranta arundinacea*) in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	80.75 g	Total ascorbic acid	1.9 mg
Energy	65 kcal	Thiamine	0.143 mg
Protein	4.24 g	Riboflavin	0.059 mg
Total lipid (fat)	0.20 g	Niacin	1.693 mg
Carbohydrate, by difference	13.39 g	Vitamin B-6	0.266 mg
Total dietary fibre	1.3 g	Folate	338 µg_DFE
Calcium	6 mg	Vitamin B-12	0.00 µg
Iron	2.22 mg	Vitamin A	1 µg_RAE
Magnesium	25 mg	Vitamin A	19 IU
Phosphorus	98 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	454 mg	Vitamin D	0 IU
Sodium	26 mg	Fatty acids, total saturated	0.039 g
Zinc	0.63 mg	Fatty acids, total monounsaturated	0.004 g
		Fatty acids, total polyunsaturated	0.092 g

within 2 days and the cultivar Creole within 7 days of harvesting (Kay 1987).

Asian spinach

Brassica spp., *Chrysanthemum* spp., *Ipomea* spp. There are various species and varieties, especially of *Brassica*, that are grown for their leaves and have similar postharvest requirements. These include:

- Chinese cabbage, *B. pekinensis*
- Chinese kale, jie lan, gai lan, *B. alboglabra* (Figure 6).
- Chinese mustard, jie cai, *B. juncea* (Figure 7).
- Choi sum, cai xin, *B. parachinensis* *B. rapa* var. *parachinensis* (Figure 8).
- Mibuna, mizuna, *B. rapa* var. *nipposinica*
- Pak choi, bai cai, *B. chinensis*, *B. chinensis* var. *pekinensis*, *B. rapa* var. *chinensis* (Figure 9).
- Tatsoi, *B. rapa* var. *rosularis*
- Tong hao, *Chrysanthemum spatiosum* (Figure 10).
- Water spinach, tong cai, *Ipomea reptans*, *I. aquatica*.

Generally 0 °C and humidity as close to 100% r.h. as possible are the optimum storage conditions for Asian spinach. O'Hare *et al.* (2000) found that at retail temperatures shelf life can be severely curtailed



Figure 6 Chinese Kale *Brassica alboglabra*. (Photo: Dr Wei Yuqing. Reproduced with permission.)



Figure 8 Choi Sum, *Brassica parachinensis*, *B. rapa* var. *parachinensis*. (Photo: Dr Wei Yuqing. Reproduced with permission.)

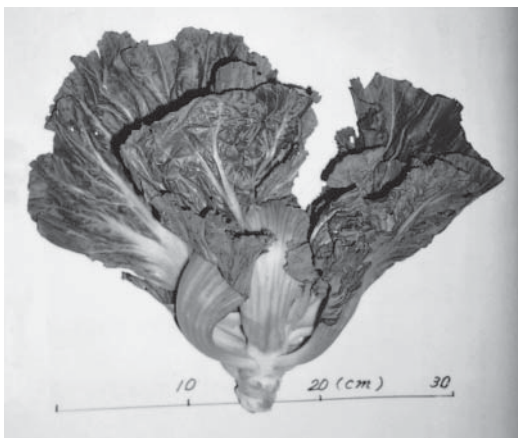


Figure 7 Chinese Mustard, *Brassica juncea*. (Photo: Dr Wei Yuqing. Reproduced with permission.)

because of leaf yellowing. They also recommended controlled atmosphere storage to reduce losses as follows:

- Chinese mustard in 10 °C with 2% O₂ and 5% CO₂ had increased shelf life by 153% compared to cold storage alone.

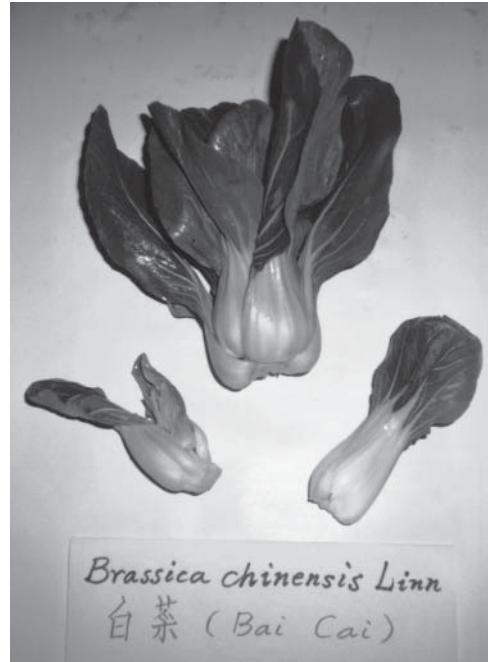


Figure 9 Pak Choi, *Brassica chinensis*, *B. chinensis* var. *pekinensis*, *B. rapa* var. *chinensis*. (Photo: Dr Wei Yuqing. Reproduced with permission.)

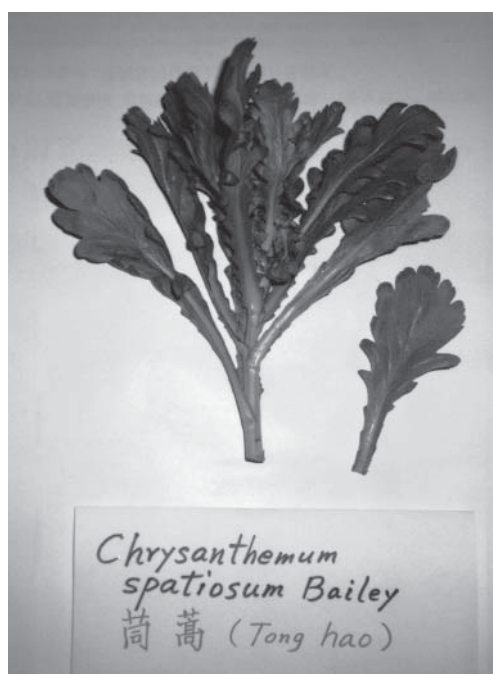


Figure 10 Tong Hao, *Chrysanthemum spatiosum*. (Photo: Dr Wei Yuqing. Reproduced with permission.)

- Choy sum (choi sum) in 10 °C with 2% O₂ and 5% CO₂ had increased shelf life by 105% compared to cold storage alone.
- Mibuna in 10 °C with 2% O₂ and 5% CO₂ had increased shelf life by 86% compared to cold storage alone. Mibuna, which was the least tolerant of CO₂, had a 70% increase in shelf life in storage with 2% O₂ and ambient CO₂.
- Mizuna in 10 °C with 2% O₂ and 5% CO₂ had increased shelf life by 40% compared to cold storage alone.
- Tatsoi in 10 °C with 2% O₂ and 5% CO₂ had increased shelf life by 153% compared to cold storage alone.

Asparagus

Liliaceae

Asparagus officinalis L., *A. officinalis* subspecies *prostratus*. It is a native of Europe and has been cultivated since the time of the ancient Greeks. It is a rare native plant occurring on grassy cliffs close to

Table 7 Chemical content of asparagus spears in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.22 g	Thiamine	0.143 mg
Energy	20 kcal	Riboflavin	0.141 mg
Protein	2.20 g	Niacin	0.978 mg
Total lipid (fat)	0.12 g	Vitamin B-6	0.091 mg
Carbohydrate, by difference	3.88 g	Folate	52 µg_DFE
Total dietary fibre	2.1 g	Vitamin B-12	0.00 µg
Sugars, total	1.88 g	Vitamin A	38 µg_RAE
Calcium	24 mg	Vitamin A	756 IU
Iron	2.14 mg	Vitamin E (α-tocopherol)	1.13 mg
Magnesium	14 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	52 mg	Vitamin D	0 IU
Potassium	202 mg	Vitamin K (phylloquinone)	41.6 µg
Sodium	2 mg	Fatty acids, total saturated	0.040 g
Zinc	0.54 mg	Fatty acids, total monounsaturated	0.000 g
Total ascorbic acid	5.6 mg	Fatty acids, total polyunsaturated	0.050 g

the sea. The plant is a perennial and the part that is eaten is the young shoots, which are called spears. They arise from the rootstock as it begins to grow in spring after over winter dormancy. The chemical content of asparagus spears which was given by USDA Nutrient Database (USDA 2012a) is shown in Table 7. Total world production in 2010 was estimated by FAO (2012) as 7,833,327 tonnes.

Harvesting and handling

If not harvested the spears continue to elongate into long spindly stems and produce fibres for support, and eventually they produce feathery leaves that are used in floristry. Spears should be harvested before fibres have been produced so that they are crisp and tender. Villanueva Suarez *et al.* (1999) found that the most important postharvest changes in the spears corresponded to increases in xylose and glucose from insoluble dietary fibre (from 2.62 to 5.14 and 7.50 to 10.14 g 100 g⁻¹ dry matter after 21 days of storage, respectively) and decreases in galactose (from 1.43 to 0.93 g 100 g⁻¹) from soluble dietary fibre. In practice they are normally harvested when the shoots are 10–15 cm above ground by cutting them off at ground level. During the harvest season this is

usually every 1–3 days. They are often harvested with a section of tough white butt to protect them from mechanical injury during handling. For certain markets they are harvested with a special knife when the tips are just beginning to emerge from the soil. The spears are cut off about 20 cm below ground. In this case the asparagus is white.

In order to preserve their freshness directly after harvesting the spears can be placed upright in field boxes, which may include a layer of damp moss at the bottom. Spears must be handled gently. In experiments Lallu *et al.* (2000) found that impact on apical tissues after drops from 0, 50, 100 or 150 mm resulted in 0, 34, 36 and 64% tip rot, respectively, after 5 days at 20 °C and 93–95% r.h.

Flores-Rojas *et al.* (2009) tested two commercially available spectrophotometers that differed primarily in terms of measurement principles and evaluated them against maximum shear force and cutting energy of the cultivar UC-157. They reported that NIR spectroscopy was a promising technology for predicting intact green asparagus texture and that the two spectrophotometers tested provided a similar degree of accuracy.

Hot water treatment

Immersing spears in water at 47.5 °C for 2–5 min and cooling as soon as possible after the heat treatment prevented curvature during 7 days of storage at 10 °C. Treatment at a higher temperature and/or for longer periods resulted in an unacceptable decline in overall appearance. Treatment temperature and duration needed to be adjusted for spear diameter; with small diameter spears required a shorter exposure time or lower temperature (Paull and Chen 1999).

Pre-cooling

Villanueva Suarez *et al.* (1999) showed that the speed at which fibre formation processes was proportional to temperature, so rapid cooling was recommended. A 4-h delay in cooling resulted in an average 40% increase in shear force because of tissue toughening (Hernandez-Rivera *et al.* 1992). In a study where spears were held at 18 °C and 50% r.h. for different periods until they lost 0, 2, 4, 6 or 8% in weight, then stored at 0.5 °C it was found that spears which had lost 8% in weight were

unsaleable after 14 days of storage, while those that had lost 0% in weight were still saleable after 28 days (Karup 1990). In a comparison of different pre-cooling methods, overall quality was marginally higher, and weight loss significantly less, in hydro-cooled spears than in forced-air or passively cooled spears. It was therefore recommended that spears are hydrocooled or forced-air cooled within 4–12 h of harvest (Lallu *et al.* 2000). A.K. Thompson (unpublished data) working in a processing factory in Korea found that they could be successfully hydrocooled within 2 min. Vacuum cooling was less successful. After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of –1.7 to 0 °C the spears' temperature fell from 20–22 to 7 °C (Barger 1963).

Postharvest physiology

Since the spears are elongating stems the respiration rate is very high especially directly after harvest. Respiration rate also depends on storage temperature. However, rates declined rapidly after harvest (Table 8). Respiration rate was strongly affected by temperature, and also by the O₂ level in the storage atmosphere (Table 9). Also the effect of reduced O₂ was greater if the storage temperature was higher. It is difficult to explain the large differences in the respiration rates given by Lipton (1990) and Robinson *et al.* (1975) since the latter measured the rate within 24 h of harvesting.

Ethylene production was low to intermediate, increased with time after harvest and varied with where the spears were cut relative above or below the soil surface (Lipton 1990). Exposure to ethylene accelerated fibre formation (Hennion *et al.* 1992).

Table 8 Effects of storage temperature and time after harvest on the respiration rate of asparagus spears in milligrams carbon dioxide per kilogram per hour (source: adapted from Lipton 1990)

Storage temperature (°C)	Time after harvest (h)		
	6	24	72
0	80	60	40
5	145	105	65
10	305	215	120
15	325	235	160
20	500	270	185

Table 9 Effects of temperature and reduced O₂ level on the respiration rate as CO₂ production in milligrams per kilogram per hour of asparagus spears (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	28	44	63	105	127
In 3% O ₂	25	—	45	—	75

Storage

Spears may be stored with their butts in water. This technique has been used in processing plants for overnight storage (A.K. Thompson, unpublished data). For the cultivar Limbras 10, spears were harvested at intervals during a 24-h cycle. They exhibited a clear diurnal pattern in postharvest shelf life, with spears harvested at 0200 h lasting 1.1 days longer at 20 °C than spears harvested at 1400 h (Lill and Borst 2001). Their shelf life at 20 °C was said to be only 1 day (Mercantilia 1989). Spears will freeze at about -1.4 to -1.1 °C (Wright 1942) or -0.89 to -0.61 °C (Weichmann 1987). Lutz and Hardenburg (1968) reported chilling injury after storage at 0 °C for more than 10 days. However, refrigerated storage recommendations include:

- 0.6 °C and 90% r.h. (Wardlaw 1937).
- 0–2 °C and 80% r.h. for 21–50 days (Wardlaw 1937).
- 0 °C and 95–98% r.h. for a maximum of 1 week (Wardlaw 1937).
- 0–0.5 °C and 85–95% r.h. for 2–4 weeks (Anonymous 1967).
- 0–1.7 °C and 95% r.h. for 3 weeks (Phillips and Armstrong 1967, Anonymous 1968).
- 0 °C and 95% r.h. for up to 10 days (Shipway 1968).
- 0 °C and 95% r.h. for 3–4 weeks (Pantastico 1975).
- 4–5 °C and high humidity for up to 21 days (Tindall 1983).
- 0 °C and 90–95% r.h. for 14 days (Mercantilia 1989).
- 4 °C for 7 days (Mercantilia 1989).
- 8 °C for 4 days (Mercantilia 1989).
- 2.2 °C and 90–95% r.h. for 14–21 days (SeaLand 1991).
- 0 °C and 95–100% r.h. for 14–21 days (white) (SeaLand 1991).
- 0–2 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1991).

- 0–2 °C and 95–99% r.h. for 14–21 days (King *et al.* 1993).

In an experiment where the temperature fluctuated from the average 6 °C by ± 5 , ± 3 or ± 1 °C every 12 or 6 h Ito and Nakamura (1985) found that the spears deteriorated increasingly rapidly with increasing amplitude of fluctuation.

Controlled atmosphere storage

Lill and Corrigan (1996) showed that during storage at 20 °C, spears stored in 5–10% O₂ + 5–15% CO₂ had an increased postharvest life from 2.6 days in air to about 4.5 days. CO₂ levels of 40–60% can be applied at 5 °C for up to 4 days without affecting sensory quality and may be used as an insect disinfestation treatment (Corrigan and Carpenter 1993). Lipton (1968) showed that levels of 10% CO₂ could be injurious, causing pitting, at storage temperatures of 6.1 °C, but at 1.7 °C no CO₂ injury was detected. However, in atmospheres containing 15% CO₂ spears were injured at both temperatures. Signs of CO₂ injury are small to elongated pits, generally first observed just below tips. Severe CO₂ injury can result in ribbiness. At O₂ levels below 2%, off-odours and discolouration may develop. Lipton also showed that storage in 10% CO₂ reduced rots because of *Phytophthora*, but in atmospheres containing 5% CO₂ there were no effects. Other work has also shown that fungal development during storage could be prevented by flushing with 30% CO₂ for 24 h or by maintaining a CO₂ concentration of 5–10% (Andre *et al.* 1980a). Hardenburg *et al.* (1990) indicated that brief (unspecified) exposure to 20% CO₂ can reduce soft rot at the butt end of spears. McKenzie *et al.* (2004) found that storage in 5% O₂ + 10% CO₂ maintained the activity of several sugar-metabolizing enzymes at, or above, harvest levels compared with storage in air, where activities fell. Controlled atmosphere storage also eliminated the increase in acid invertase activity found during storage in air. There were significant differences in the pool sizes of sugars in the different compartments (vacuole, cytoplasm, free space). Controlled atmosphere storage also resulted in a lower concentration of glucose in the free space but it appeared to engage the ethanolic fermentation pathway but only transiently. Controlled atmosphere storage may have permitted more controlled use of

which ever vacuole sugar the tissue normally drew upon (fructose) and delayed an increase in plasma membrane permeability. Other storage recommendations include:

- 1 °C in 10% CO₂ + 5–10% O₂ (Monzini and Gorini 1974)
- 4 °C with 10–14% CO₂ and high humidity. At higher temperatures these levels of CO₂ could be injurious, but levels of 5% CO₂ had no effects, nor did reduced O₂ (J.R. Stow 1977, personal communication).
- 3 °C with 2% O₂ and bags of slaked lime for 42 days (McKeown and Loughheed 1981)
- 0–5 °C with 5–10% CO₂ and 21% O₂, which had a good effect but limited commercial use (Kader 1985, 1992).
- 5 °C with a maximum of 10% CO₂ and a minimum of 10% O₂ (Fellows 1988)
- 1–5 °C with 10–14% CO₂ and 21% O₂, which had only a slight effect (Saltveit 1989).
- 0 °C with 12% CO₂ or at 5 °C or just above at 7% CO₂ retarded decay and toughening and brief exposure to 20% CO₂ can reduce soft rot at the butt end (Hardenburg *et al.* 1990).
- 0 °C with 5–10% CO₂ and 20% O₂ (SeaLand 1991).
- 0 °C and 95% r.h. in 9% CO₂ + 5% O₂ (Lawton 1996).
- 0–3 °C in 10–14% CO₂ (Bishop 1996).

Modified atmosphere packaging

Villanueva Suarez *et al.* (1999) found that the changes observed in the fibre of the non-packed asparagus stored in air at 20 °C were more rapid and pronounced than those in polyethylene bags in either air or a modified atmosphere of 15% O₂, 10% CO₂ and 75% nitrogen. Losses of glucose, uronic acids, arabinose and galactose were greater in packed spears stored in a modified atmosphere than in packed spears stored in air. Storage at 2 °C in modified atmosphere packaging retained their sensory quality and ascorbic acid levels. In several trials cooling to 1 °C within 6–8 h of harvest, followed by storage at 1 °C in PE bags with silicon elastomer windows kept them in good condition for 20–35 days (Andre *et al.* 1980b). Lill and Corrigan (1996) experimented with different modified atmosphere packs and found that they

all significantly extended the shelf life of the spears by between 83 and 178%, depending on film type, compared to those not wrapped. The least permeable films (W.R. Grace RD 106 and Van Leer Packaging Ltd) gave the longer shelf life extension; the former film had 2.5–3.5% CO₂ + 4.1–9.7% O₂ and the latter 3.6–4.6% CO₂ + 2.0–4.5% O₂ equilibrium gas content at 20 °C.

Hypobaric storage

In storage in 55–60 mm Hg at 3 °C spears retained their green colour and firmness for 42 days (McKeown and Loughheed 1981). At 0 °C and 20, 40 or 80 mm Hg Dilley (1990) found that spears could be kept in marketable condition for 4–6 weeks with better ascorbic acid retention at 20 mm Hg than at the other hypobaric conditions. Li and Zhang (2006) reported an extension in postharvest life of green asparagus in storage in 112.5 ± 37.5 mm Hg. Li *et al.* (2006) found that at room temperature storage life of asparagus was 6 days, in refrigerated storage it was 25 days and in hypobaric storage it was up to 50 days. They also found that hypobaric storage significantly delayed postharvest senescence reduced respiration rate and chlorophyll reduction and improved sensory quality.

Diseases

Bacterial soft rot, caused by *Pectobacterium carotovora*, *Pseudomonas* and *Erwinia* resulted in decay in the form of soft rot pits most frequently on the tips or the butts. Storage at less than 5 °C can restrict development of the bacterial diseases. The following fungal diseases have been reported postharvest on asparagus:

- Anthracnose *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. *C. dematium* (Pers.) Grove.
- Blue mould rot *Penicillium aurantiogriseum* Dierckx.
- Fusarium spear spot *Fusarium oxysporum* (Schlecht) emend. Snyder & Hans. f. sp. *asparagi* (Cohen & Heald) *F. redolens* Wollenw.
- Grey mould shoot blight *Botrytis cinerea* Pers.:Fr.
- Phytophthora spear and crown rot *Phytophthora megasperma* Drechs.
- Purple spot *Pleospora herbarum* (Pers.:Fr) Rabenh. *Stemphylium vesicarium* Wallr. [anamorph].

- Rhizoctonia crown rot *Rhizoctonia solani* Kühn *Rhizoctonia* sp.
- Watery soft rot *Sclerotinia sclerotiorum* (Lib.) de Bary.

Aubergines

Solanaceae

Solanum melongena L. Other common names include brinjal, egg plant and melongene. It originated in the Indian sub-continent where it was first cultivated. It was subsequently taken to Africa by Persians and to Spain by Arabs (Purseglove 1972). It is a perennial usually grown as an annual with erect branched tough stems. The fruit is a pendant berry, which can be spherical, ovoid to oblong in shape. Most cultivars are dark purple in colour although white, yellow and variegated cultivars are grown.

Concellón *et al.* (2012) reported a gradual but continuous accumulation of antioxidants in the cultivar Lucía stored at 10 °C increasing by 60% after 14 days of storage. The major phenolic detected by HPLC was chlorogenic acid, an ester between caffeic and quinic acids, which accumulated in fruit maintained at 10 °C. The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 10. Total world production in 2010 was estimated by FAO (2012) as 43,891,773 tonnes.

Harvesting

The fruit are harvested when they reach a size that the market requires, but if this is delayed too long they can become seedy, dull and fibrous (Pantastico 1975).

Prestorage treatment

Massolo *et al.* (2011) harvested the cultivar Lucía at commercial maturity, treated them with 1-MCP at 1 µl L⁻¹ for 12 h at 20 °C and then stored them at 10 °C for 21 days. The calyxes of fruit treated with 1-MCP showed reduced damage and remained greener. Fruit browning was prevented and they had lower weight loss and delayed senescence compared to those that had not been treated. Pulp browning was associated with lower accumulation of total phenolics and reduced activity of PAL, PPO and POD involved in the oxidation of phenolics compounds. Barbagallo *et al.* (2012) found that dipping

Table 10 Chemical content of aubergines fruits in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.41 g	Thiamine	0.039 mg
Energy	24 kcal	Riboflavin	0.037 mg
Protein	1.01 g	Niacin	0.649 mg
Total lipid (fat)	0.19 g	Vitamin B-6	0.084 mg
Carbohydrate, by difference	5.70 g	Folate	22 µg_DFE
Total dietary fibre	3.4 g	Vitamin B-12	0.00 µg
Sugars, total	2.35 g	Vitamin A	1 µg_RAE
Calcium	9 mg	Vitamin A	27 IU
Iron	0.24 mg	Vitamin E (α-tocopherol)	0.30 mg
Magnesium	14 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	25 mg	Vitamin D	0 IU
Potassium	230 mg	Vitamin K (phylloquinone)	3.5 µg
Sodium	2 mg	Fatty acids, total saturated	0.034 g
Zinc	0.16 mg	Fatty acids, total monounsaturated	0.016 g
Total ascorbic acid	2.2 mg	Fatty acids, total polyunsaturated	0.076 g

of minimally processed F₁ hybrid Birgah in calcium ascorbate (0.15 g⁻¹) was effective against degradative enzymatic activities that improving consumer overall acceptance that were acceptable up to 7 days of storage at 4 ± 0.5 °C. There was inhibition of PPO, pectin methylesterase, polygalacturonase, a significant reduction of browning and softening in comparison to those not treated.

Postharvest physiology

Aubergine was classified as a non-climacteric fruit by Massolo *et al.* (2011) and Inaba *et al.* (1989). There was an increased respiration rate in response to ethylene at 100 µl L⁻¹ for 24 h over the temperature range of 20–35 °C, but the effect was much reduced at lower temperatures. Levels of decay and fruit stalk abscission were increased in the presence of ethylene (Schouten and Stork 1977).

Storage

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 3–4 days (Mercantilia 1989). They will freeze at about –1.0 to –0.7 °C (Wright 1942) or –0.94 to –0.78 °C

(Weichmann 1987). Chilling injury was reported after 32 days of storage at 7.2 °C in the form of internal browning (Wardlaw 1937). Chilling injury can result in surface scald, browning, pitting and excessive decay that may not be apparent until the fruit are removed from storage (Wardlaw 1937, Lutz and Hardenburg 1968). Concellón *et al.* (2012) found that the cultivar Lucía stored at 0 °C had higher electrolyte leakage and surface scalds and pulp browning. The symptoms of chilling injury can be confused with CO₂ injury. Refrigerated storage recommendations were:

- 0–4.4 °C for 2–4 weeks (Platenius *et al.* 1934).
- 7.2–10 °C and 80–85% r.h. (Wardlaw 1937).
- 10–15.6 °C and 80–85% r.h. for 10 days (Wardlaw 1937).
- 7.2–10 °C and 90% r.h. for 1 week (Lutz and Hardenburg 1968).
- 10 °C and 75% r.h. for 5–8 days with 3.1–3.6% loss (Heydendorff and Dobreanu 1972).
- 10–12.8 °C and 92% r.h. for 2–3 weeks with 9.6% loss (Pantastico 1975).
- 8.3–10 °C and 85–90% r.h. for 4 weeks with 17.7% loss (Pantastico 1975).
- 10–13 °C and 90–95% r.h. for 10–14 days with a weight loss of about 10% (Tindall 1983).
- 8–10 °C and 90–95% r.h. for 10–14 days (Mercantilia 1989).
- 8–12 °C and 90–95% r.h. for 7–10 days (Hardenburg *et al.* 1990).
- 10 °C and 90–95% r.h. for 10–14 days (SeaLand 1991).
- 8–12 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1991).

Controlled atmosphere storage

Sayed *et al.* (2000) measured the respiration rate of aubergines in different CO₂ and O₂ concentrations. They found that in 0% CO₂ the respiration rate was 60 mg CO₂⁻¹ kg⁻¹ h⁻¹ while in 6.7% CO₂ it was 30 mg CO₂⁻¹ kg⁻¹ h⁻¹. Also in 20.6% O₂ it was 60 mg CO₂⁻¹ kg⁻¹ h⁻¹, while in 1.7% O₂ it was only 28 mg CO₂⁻¹ kg⁻¹ h⁻¹. This indicates that the controlled atmosphere storage could be beneficial to aubergines. High CO₂ in the storage atmosphere can cause surface scald browning, pitting and excessive decay, these symptoms are similar to those caused by

chilling injury (Wardlaw 1937). CO₂ concentrations of 5, 8 or 12% during storage all resulted in CO₂ injury, characterized by external browning without tissue softening (Mencarelli *et al.* 1989). Viraktamath *et al.* (1963, quoted by Pantastico 1975) claimed that atmospheres containing CO₂ levels of 7% or higher were injurious. Storage in 0% CO₂ with 3–5% O₂ was recommended by SeaLand (1991).

Modified atmosphere packaging

Modified atmosphere packaging prolonged the shelf life and flesh firmness compared with those stored non-wrapped (Arvanitoyannis *et al.* 2005).

Avocado

Lauraceae

Persea americana Mill. synonymous with *P. gratissima* Gaertn. Some authorities considered the Mexican race a separate species *P. drymifolia* Cham. & Schlecht. or a separate variety *Persea americana* var. *drymifolia* Mex. Morton (1987) gave the following classification: West Indian as *P. americana* Mill. var. *americana* (*P. gratissima* Gaertn.), Mexican as *P. americana* Mill. var. *drymifolia* Blake (*P. drymifolia* Schlecht. & Cham.) and Guatemalan as *P. nubigena* var. *guatemalensis* L. Wms. Other common names include aguacate, alligator pear, midshipmen's butter and pulta. It is native to Central America, and Purseglove (1972) commented that early Spanish colonists recorded it being cultivated in Mexico and Peru but not in the Caribbean Islands. Morton (1987) reported that it originated in southern Mexico but was cultivated from the Rio Grande to Central Peru long before the arrival of Europeans. It was introduced into Spain in 1601, to Jamaica in 1650 (or 1696, Morton 1987) and to the Philippines near the end of the 16th century, the Dutch East Indies by 1750 and Mauritius in 1780. Most of its spread in Asia was in the mid-19th century. It was first reported in Florida in 1833, in California in 1856 and in Zanzibar in 1892. Total world production in 2010 was estimated by FAO (2012) as 3,891,626 tonnes.

Fruit are produced on trees that can grow up to 20 m high with small, pale-green or yellow-green flowers that are borne profusely in racemes near the branch tips. Growth is in flushes, and flowers

are bisexual, have single-celled ovaries and are produced in panicles at the end of branches. Fruits are single-seeded berries globose or pyriform up to 20 cm long. Small seedless cultivars (Figure 11) have been developed but do not seem to have made an appreciable impact on the market. The exocarp is from green to purple in colour and with a yellowish green mesocarp. There are three ecological races of *P. americana* (Condit 1919, Purseglove 1968, Thompson *et al.* 1971, Chen *et al.* 2009):

- Mexican race is a native of the Mexican highlands. Leaves are anise-scented when crushed. It is most tolerant of cold growing conditions and has an oil content of up to 30%. Fruit are small, up to 225 g, with a smooth skin and comparatively large seed that is often loose in the cavity. It takes 6–8 months from flowering to harvest.
- Guatemalan race is a native of the Guatemalan highlands. Leaves are not scented. It has an oil content of 8–15% and is less cold tolerant than Mexican. Fruits are large and weigh up to 1 kg and have a thick, hard, tough, brittle skin that may be warty with usually a small seed held tightly in the central cavity. It takes 9–12 months from flowering to harvest.
- West Indian race is a native of the Central American lowlands. It is the least cold tolerant and has an oil content of only 3–10%. Leaves are not scented. Fruit have a leathery smooth pliable skin that is thick but not as thick as the Guatemalan. Seeds are large and often loose in the cavity. It is often considered to have a better flavour but a shorter postharvest life.

Chen *et al.* (2009) confirmed that the substantial genetic differentiation among the three ecological races of *P. americana* corresponded to the defined horticultural races of avocado. Previously undetected genetic differentiation has two sub-populations from Central Mexico based on altitude and latitude. Many cultivars are hybrids including Fuerte, Greengold and Sharwil that are Mexican × Guatemalan hybrids, Kahalu and Semi that are Guatemalan × West Indian hybrid and Lula whose female parent is Guatemalan and the male parent is unknown but probably West Indian. Due to their oil content avocados have a low freezing point of about -2.8 to -2.6 °C depending on their race and cultivar (Wright 1942). The chemical



Figure 11 Small seedless avocados alongside a conventional avocado. See colour plate section. (Photo: Fernando Cosman.)

content which was given by USDA Nutrient Database (2012a) is shown in Table 11.

Rootstocks

Most avocados are grafted on to root stocks to control the size and vigour of the tree. In some work in South Africa by Smith and Köhne (1992) it was shown that the cultivar Fuerte grown on different seedling rootstocks showed a large variation in quality of fruit, which could affect their postharvest behaviour, as well as yield (Table 12). Marques *et al.* (2003) compared preharvest and postharvest qualities of the cultivar Hass that had been grafted onto Velvick or Duke 7 rootstocks. They found that the rootstock could affect fruit quality, vascular browning, rotting and their mineral composition.

Harvesting

Oil content of the fruit may be used to determine the harvest maturity of avocados. The Agricultural Code of California specifies '... avocados, at the time of picking and at all times thereafter, shall contain not less than 8% of oil by weight of the avocado excluding the skin and seed'. Eaks (1990) in California found that during development on the tree the oil content in Fuerte increased to just below 20% then levelled off, and in Hass there was a progressive increase throughout development to just over 15% before levelling off. During subsequent storage of the fruit at temperatures in the range of 0–20 °C the oil content remained constant. Oil content in avocados is related to moisture content, and in South Africa they specify

Table 11 Chemical content of avocado fruits in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	All commercial varieties	California	Florida
Water (g)	73.23	72.33	78.81
Energy (kcal)	160	167	120
Protein (g)	2.00	1.96	2.23
Total lipid (fat) (g)	14.66	15.41	10.06
Carbohydrate, by difference (g)	8.53	8.64	7.82
Total dietary fibre (g)	6.7	6.8	5.6
Sugars, total (g)	0.66	0.30	2.42
Calcium (mg)	12	13	10
Iron (mg)	0.55	0.61	0.17
Magnesium (mg)	29	29	24
Phosphorus (mg)	52	54	40
Potassium (mg)	485	507	351
Sodium (mg)	7	8	2
Zinc (mg)	0.64	0.68	0.40
Total ascorbic acid (mg)	10.0	8.8	17.4
Thiamine (mg)	0.067	0.075	0.021
Riboflavin (mg)	0.130	0.143	0.053
Niacin (mg)	1.738	1.912	0.672
Vitamin B-6 (mg)	0.257	0.287	0.078
Folate (µg_DFE)	81	89	35
Vitamin B-12 (µg)	0.00	0.00	0.00
Vitamin A (µg_RAE)	7	7	7
Vitamin A (IU)	146	147	140
Vitamin E (α-tocopherol) (mg)	2.07	1.97	2.66
Vitamin D (D2 + D3) (µg)	0.0	0.0	0.0
Vitamin D (IU)	0	0	0
Vitamin K (phylloquinone) (µg)	21.0	21.0	–
Fatty acids, total saturated (g)	2.126	2.126	1.960
Fatty acids, total monounsaturated (g)	9.799	9.799	5.513
Fatty acids, total polyunsaturated (g)	1.816	1.816	1.676

Table 12 Effect of clonal rootstock on the yield and quality of Hass avocados (source: adapted from Smith and Köhne 1992)

Rootstock	Yield (kg per tree)	Fruit internally clean percentage
Thomas	92.7	96
Duke 7	62.1	100
G 755	12.1	100
D 9	7.4	64
Barr Duke	3.1	70

Table 13 Minimum moisture content for South Africa avocado fruit for export (source: adapted from Smith and Köhne 1992)

Cultivar	Moisture content (%)
Fuerte	80
Pinkerton	80
Hass	77
Ryan	77
Edranol	74

the minimum moisture content for export (Table 13). Blumenfeld (1993) also showed that there was good correlation between taste and oil content and dry matter and oil content for avocados grown in Israel and also recommended that the rate of dry matter accumulation could be used to predict optimum harvest time. However, these methods of stipulating harvest maturity have little relevance to avocados grown in the tropics for two reasons. The first reason is that it is based on a sampling technique where it is assumed that the sample of fruit on which the oil or dry matter analysis has been taken is representative of the whole field. In the subtropics, for example in California, South Africa and Israel, there are distinct seasons and flowering of avocados occurs after a cold season and the trees tend to flower and thus set fruit over a short period of time. Fruit of the same cultivar in one orchard will have fruit that mature at about the same time, and so a representative sample can be taken. In the tropics the flowering period, even on the same tree, is over a much more protracted period and so there is a wide range of fruit maturities. It is rarely possible, therefore, to obtain a representative sample. There may even be fully mature fruit and flowers on the same tree at the same time. Also, the ones grown in the subtropics tend to be of the Mexican or Guatemalan races or a cross between the two, while in the tropics the West Indian race of avocados is often more common and this race has fruit which have a much lower oil content even when fully mature. In South Africa the early maturing fruit tended to have better quality and postharvest characteristics than those that matured later. Milne (1993) showed, in studies over two seasons, where early picked fruit had an average of over 80% 'clean fruit', while late picked fruit had an average of just over 50%. This quality effect may have an affect on storage to extend the

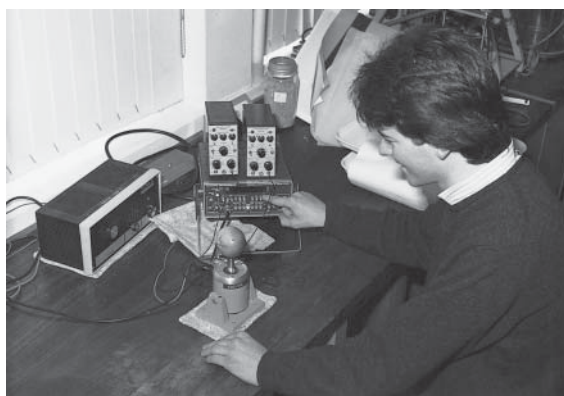


Figure 12 Equipment which puts vibrational energy into fruit and measures its response being tested on apples. (Photo: A.J. Hilton. Reproduced with permission of Cranfield University.)

season of availability because the fruit that may be required for storage are usually those of the poorest quality.

Nuclear magnetic resonance has also been shown to correlate well with oil content in avocados (McCarthy *et al.* 1989), but the technology is expensive and no records could be found of its commercial use. Self *et al.* (1993) have shown that there is a relationship between ultrasonic velocity and the ripeness of avocados. Acoustic and vibration tests equipment puts vibration energy into a fruit, and measures its response to this input (Figure 12). Good correlations have been found using the second resonant frequency to determine avocado maturity (Darko 1984, Punchoo 1988). A sensor system for automatic non-destructive sorting of firm 'tree-ripe' avocado fruits used vibrational excitement of one side of the fruit, while measuring the transmitted vibration energy on the other. Special signal processing hardware and software were developed for computing several alternative firmness indices, which were highly correlated with values obtained by the standard destructive piercing force test method. Optimal classification algorithms were developed whereby fruit could be classified into two or three firmness grades (Peleg *et al.* 1990).

Prestorage treatments

In his review Yahia (2011) reported that calcium content of fruit can affect their ripening and rotting. Postharvest application of calcium has also been

shown to inhibit ripening of avocados (Wills and Tirmazi 1982). The calcium was applied by vacuum infiltration (250 mm Hg) with calcium chloride at concentrations within the range of 1–4%; higher concentrations could result in skin damage. These treatments were found to significantly delay ripening without affecting fruit quality. Treatment of avocados prior to storage in atmospheres of total nitrogen was also shown to retard their ripening (Pesis *et al.* 1993). Application of 1-MCP delayed ripening and reduced flesh greying and vascular browning that was associated with ripening during storage where storage times are long, or temperature management is poor but did not reduce external symptoms of chilling injury in the cultivar Hass (Pesis *et al.* 2002).

Cold storage of the cultivars Gold Nijisseiki and Hosui in addition to 1-MCP treatment was effective for long-term storage (Itai and Tanahashi 2008). Preclimacteric Booth 7 fruit were treated for 1 min with aqueous 1-MCP at 1.86 and 9.3 mmol m⁻³ (100 and 500 µg L⁻¹) 1 day after harvest when their ethylene production was less than 0.05 ng kg⁻¹ s⁻¹. Both concentrations strongly suppressed softening, delayed ethylene production and delayed the climacteric peak. Seven days after harvest when the ethylene production was ≈ 65% of maximum and the fruit were considered mid-climacteric, there was a complete loss of sensitivity to 1-MCP at 1.86 or at 9.3 mmol m⁻³ a diminished loss (Zhang *et al.* 2012). There was improved efficacy of 1-MCP at elevated doses and following reduction of internal ethylene concentration in suppressing ripening of mid-climacteric fruit. They considered that this was consistent with the model that internal ethylene concentration strongly influences 1-MCP sensitivity in climacteric fruit that have been initiated to ripen. Preclimacteric Tower II and Booth 7 were treated with 1-MCP for 12 h at 20 °C then half of the fruit were waxed with Sta-Fresh 819F®, FMC Co. after 1-MCP treatment by Jeong *et al.* (2000). The fruit were subsequently stored at 13 °C or 20 °C at 85% r.h. 1-MCP and waxing delayed the ripening of Tower II avocados stored at 20 °C. Fruit treated with both 1-MCP and wax had better retention of green peel colour and fruit firmness, and the delayed climacteric pattern of ethylene evolution and respiration rates. Waxing reduced weight loss and retarded softening, but did not delay climacteric ethylene evolution and respiration rates. While firmness of control

fruit decreased from greater than 100–20 N in as few as 7 days at 20 °C, fruit treated with both 1-MCP and wax reached 20 N over 11 days at 20 °C. The firmness of Booth 7 avocados treated with both 1-MCP and wax decreased from greater than 170–20 N over a 5-week period at 13 °C. Current studies are addressing the nature of the dramatic decrease in firmness of MCP-treated fruit.

Postharvest physiology

Avocado is classified as a climacteric fruit. Biale and Young (1962) showed that at both 5 and 30 °C no climacteric rise in respiration occurred in a Mexican and Guatemalan hybrid, but a climacteric occurred at all the intervening temperatures. Yearsley *et al.* (2003) showed that storage at 5 °C in 1% O₂ resulted in stress which showed itself in the biosynthesis of ethylene but levels rapidly returned to trace levels when fruit were returned to non-stressed atmospheres. No ethanol was detected in fruit after storage for up to 96 h in CO₂ levels of up to 20%.

Chilling injury

Certain cultivars were reported to be susceptible to chilling injury when stored below 13 °C (Salunkhe and Desai 1984). Symptoms of chilling injury include pitting, browning of pulp near the seed or in the tissue midway between the seed and the skin, failure to soften when transferred to a higher temperature, off-flavour, vascular strands and development of a brownish appearance. In other work chilling injury was shown to occur at 10–11.1 °C for cultivars of the West Indian race and 4.4–6.1 °C for the Mexican and Guatemalan races (Pantastico 1975). In a study of avocados from trees propagated from seed in Grenada, Thompson *et al.* (1971) showed that there was considerable variation in storage life and chilling injury symptoms between fruit from different trees (Table 14). It meant that even at 7 °C some 77% of the fruit ripened without showing symptoms of chilling injury and at 13 °C some 27% actually suffered from chilling injury. It is therefore difficult to generalize, as did Pantastico. However, it does seem clear that the Mexican and Guatemalan races are less susceptible to chilling injury than the West Indian race.

Controlled atmosphere storage can affect susceptibility to chilling injury. There were less chilling injury

Table 14 Effects of storage temperature on time from harvest to softening and chilling injury symptoms of West Indian seedling avocados (source: Thompson *et al.* 1971)

Storage temperature (°C)	Mean days to softening	Percentage affected by chilling injury after storage
7	16	23
10	13	16
13	16	27
18	9	0
27	8	0

symptoms in Booth 8, Lula and Taylor after refrigerated storage in controlled atmospheres than in refrigerated storage in air (Haard and Salunkhe 1975, Pantastico 1975). Corrales Garcia (1997) found that Hass stored at 2 or 5 °C for 30 days in air, 5% CO₂ with 5% O₂ or 15% CO₂ with 2% O₂ had higher chilling injury for fruits stored in air than the fruits in controlled atmosphere storage, especially those stored in 15% CO₂ with 2% O₂. Spalding and Reeder (1975) showed that storage of fruits at either 0% CO₂ with 2% O₂ or 10% CO₂ with 21% O₂ fruit had less chilling injury and less anthracnose during storage at 7 °C than fruits stored in air. Intermittent exposure of the cultivar Hass to 20% CO₂ increased their storage life at 12 °C and reduced chilling injury during storage at 4 °C compared to those stored in air at the same temperatures (Marcellin and Chaves 1983).

Avocados of the Fuerte cultivar will ripen normally at temperatures between 9 and 24 °C, but in the presence of 100 µl L⁻¹ ethylene, chilling injury occurred at 12 °C (Lee and Young 1984). Application of calcium to avocados could reduce their susceptibility to chilling injury during subsequent storage (Hofman and Smith 1993). Fruits stored for 4–10 weeks at 2 °C had reduced severity of chilling injury symptoms and percentage of injured fruits after they had been dipped for 30 s in methyl jasmonate at 2.5 µM for Fuerte and Hass and 10 µM for Etinger (Meir *et al.* 1996).

Storage

General recommendations for cold storage were:

- 5–10 °C and 90% r.h. for 2–4 weeks (Anonymous 1967).
- 8–12 °C and 85–90% r.h. for 2–4 weeks (unripe) (Kader 1985).

- 5–8 °C and 85–90% r.h. for 1–2 weeks (ripe) (Kader 1985).
- 20 °C for 11 days (Saucedo Veloz *et al.* 1991).

Recommendations for specific cultivars, varieties or production region were given as follows:

Anaheim

- Guatemalan, large with up to 22% oil.
- 10% CO₂ with 6% O₂ at 7 °C for 38 days compared to only 12 days in air at the same temperature (Bleinroth *et al.* 1977).

Booth 1

- Guatemalan × West Indian hybrid, medium to large with 8–12% oil.
- 4.5 °C and 85–90% r.h. for 2–4 weeks for unripe fruits (Snowdon 1991).
- 4 °C and 90–95% r.h. for 4–8 weeks (Yahia 2011).

Booth 8

- Guatemalan × West Indian hybrid medium to large with 7–14% oil.
- 4.4 °C and 85–90% r.h. for 1 month or longer (Lutz and Hardenburg 1968).
- 4.5 °C and 85–90% r.h. for 2–4 weeks for unripe fruits (Snowdon 1991).

California grown fruit

- 3.3 °C and 85–90% r.h. for 14–28 days (SeaLand 1991).
- 3–10% CO₂ with 2–5% O₂ (SeaLand 1991).

Ettinger

- 5.5 °C and 85–90% r.h. for 3–4 weeks for unripe fruits (Snowdon 1991).

Fuchs

- West Indian, medium size with 4–6% oil.
- 12.8 °C and 85–90% r.h. for 2 weeks (Lutz and Hardenburg 1968).
- 12 °C and 2% O₂ with 10% CO₂ for 3–4 weeks (Spalding and Reeder 1975).
- 10–13 °C and 85–90% r.h. for 2 weeks for unripe fruits (Snowdon 1991).
- 13 °C and 85–90% r.h. for 2 weeks (Yahia 2011).

Fuerte

- Mexican × Guatemalan hybrid with fruit weighing up to 450 g and an oil content of 18–26%.

- 7.2 °C for 2 months in 3 or 4–5% CO₂ with 3 or 4–5% O₂ which was more than a month longer than they could be stored at the same temperature in air (Overholster 1928).
- 7.2 °C for 2 month in 4–5% CO₂ with 4–5% O₂ (Wardlaw 1937).
- 5–6.7 °C had double or triple the storage life in 3–5% CO₂ with 3–5% O₂ than in air (Pantastico 1975).
- 10% CO₂ with 6% O₂ at 7 °C for 38 days compared to only 12 days in air at the same temperature (Bleinroth *et al.* 1977).
- 5.5–8 °C and 85–90% r.h. for 3–4 weeks for unripe fruits (Snowdon 1991).
- 2–5 °C and 85–90% r.h. for 1–2 weeks for ripe fruit (Snowdon 1991).
- 3–7 °C and 85–90% r.h. for 2–4 weeks (Yahia 2011).
- Both Overholster (1928) and Wardlaw (1937) showed that Fuerte stored at 45 °F (7.2 °C) had a 2-month storage life in 3 or 4–5% CO₂ + 3 or 4–5% O₂. This was more than a month longer than they could be stored at the same temperature in air. Biale (1950) also reported similar results. Pantastico (1975) showed that storage at 5–6.7 °C had double or triple the storage life in 3–5% CO₂ + 3–5% O₂ than in air. Bleinroth *et al.* (1977) recommended 10% CO₂ + 6% O₂ at 7 °C which gave a storage life of 38 days compared to only 12 days in air at the same temperature. Prestorage treatment with 3% O₂ + 97% N₂ for 24 h at 17 °C, significantly reduced chilling injury symptoms during subsequent storage at 2 °C for 3 weeks. Fruit softening was also delayed by this treatment. The treated fruit had a lower respiration rate and ethylene production not only during storage at 2 °C but also when removed to 17 °C (Pesis *et al.* 1994).

Guatemalan varieties

- 5.6–7.2 °C and 85–90% r.h. for 4 weeks with 10% loss (Pantastico 1975).
- 4 °C (Salunkhe and Desai 1984).

Gwen

- Lizana *et al.* (1993) described storage at 6 °C and 90% r.h. in controlled atmosphere conditions of 5% CO₂ with 2% O₂, 5% CO₂ with 5% O₂, 10%

CO₂ with 2% O₂, 5% CO₂ with 2% O₂, 10% CO₂ with 5% O₂, or 0.03% CO₂ with 21% O₂ (control) for 35 days followed by 5 days at 6 °C in normal air and 5 days at 18 °C to simulate shelf life. All fruit in controlled atmosphere storage retained their firmness and were in excellent quality regardless of treatment while the control fruit were very soft and unmarketable after 35 days of storage.

Hass

- Guatemalan × Mexican hybrid generally 18–22% oil but up to 35%.
- 5.5–8 °C and 85–90% r.h. for 3–4 weeks for unripe fruits (Snowdon 1991).
- 2–5 °C and 85–90% r.h. for 1–2 weeks for ripe fruit (Snowdon 1991).
- 3–7 °C and 85–90% r.h. for 2–4 weeks, with 5–7 °C for early season fruit and 4–5.5 °C for late season fruit (Yahia 2011).
- 5 °C for 6 weeks followed by 4 days at 20 °C resulted in excessive softening, browning and storage rots while 2 °C for 6 weeks followed by 4 days at 20 °C resulted in fruit of better quality (Saucedo Veloz *et al.* 1991). Lizana and Figuero (1997) compared several controlled atmosphere storage conditions and found that 6 °C with 5% CO₂ and 2% O₂ was optimum. Under these conditions they could be stored for at least 35 days and then kept at the same temperature in air for a further 15 days and still be in good condition. Corrales Garcia (1997) found that fruit stored at 2 or 5 °C for 30 days in air, 5% CO₂ with 5% O₂ or 15% CO₂ with 2% O₂ had higher chilling injury for fruits stored in air than the fruits in controlled atmosphere storage, especially those stored in 15% CO₂ with 2% O₂. In experiments described by Meir *et al.* (1993) at 5 °C, increasing CO₂ levels over the range of 0.5, 1, 3 or 8% and O₂ levels of 3 or 21% inhibited ripening (on the basis of fruit firmness and peel colour change). The most effective CO₂ concentration was 8%, with either 3 or 21% O₂; with a combination of 3% O₂ and 8% CO₂ fruits could be stored for 9 weeks. After controlled atmosphere storage, fruits ripened normally and underwent typical peel colour changes. Some injury to the fruit peel was observed, probably attributable to low O₂ concentrations. Peel damage was seen in 10% of fruits held in 3% O₂ with either 3 or 8% CO₂ but it was too slight to affect their marketability.
- Yearsley *et al.* (2003) showed that storage at 5 °C in 1% O₂ resulted in stress which showed itself in the biosynthesis of ethylene but levels rapidly returned to trace levels when fruit were returned to non-stressed atmospheres. No ethanol was detected in fruit after storage for up to 96 h in CO₂ levels of up to 20%. Lizana and Figuero (1997) compared several CA storage conditions and found that 6 °C with 5% CO₂ + 2% O₂ was optimum. Under these conditions they could be stored for at least 35 days and then kept at the same temperature in air for further 15 days and were still in good condition. Corrales Garcia (1997) found that fruit stored at 2 or 5 °C for 30 days in air, 5% CO₂ + 5% O₂ or 15% CO₂ + 2% O₂ had higher chilling injury for fruits stored in air than the fruits in CA storage. Storage in 15% CO₂ + 2% O₂ was especially effective in reducing chilling injury. Intermittent exposure to 20% CO₂ increased their storage life at 12 °C and reduced chilling injury during storage at 4 °C compared to those stored in air at the same temperatures (Marcellin and Cheves 1983). Burdon *et al.* (2008) concluded that fruit quality was better after CA storage than after storage in air, and that DCA storage was better than 'standard' CA storage. The effect of DCA was to reduce the incidence of rots when ripe. Inclusion of CO₂ at 5% in CA retarded fruit ripening but stimulated rot expression and they concluded that it should not be used for CA storage of New Zealand grown Hass. DCA prolonged fruit storage life but when removed from storage they ripened more rapidly and more uniformly with fewer rots than those from 'conventional' CA storage (Burdon *et al.* 2009). They recommended setting the DCA O₂ level as soon as possible after harvest. Fruit were stored for 6 weeks at 5 °C in different CA conditions then ripened in air at 20 °C by Burdon *et al.* (2008). Those that had been stored in less than 3% O₂ + 0.5% CO₂ ripened in 4.6 days compared with 7.2 days for those that had been stored in 5% O₂ + 5% CO₂ and 4.8 days for fruit that had been stored in air.

Lula

- It is a hybrid with Guatemalan as the female parent and the male parent is unknown. Fruit weigh up to 700 g and their oil content was 12–15%.
- 4–7 °C and 98–100% r.h. with 10% CO₂ and 2% O₂ for 8 weeks (Spalding and Reeder 1972).
- 10 °C with 9% CO₂ and 1% O₂ for 60 days (Pantastico 1975).
- 7.2 °C with 10% CO₂ and 1% O₂ for 40 days (Pantastico 1975).
- 4.4 °C and 85–90% r.h. for 1 month or longer (Lutz and Hardenburg 1968).
- 4.5 °C and 85–90% r.h. for 4–5 weeks (Snowdon 1991).
- Controlled atmosphere storage at 3–5% CO₂ and 3–5% O₂ delayed fruit softening and 9% CO₂ with 1% O₂ at 10 °C kept them in an acceptable eating quality and appearance for 60 days (Hardenburg *et al.* 1990).
- 4 °C and 90–95% r.h. for 4–8 weeks (Yahia 2011).
- Stahl and Cain (1940) recommended 3% CO₂ + 10% O₂. Storage at 10 °C in 3–5% CO₂ + 3–5% O₂ delayed fruit softening and 9% CO₂ + 1% O₂ kept them in an acceptable eating quality and appearance for 60 days (Hardenburg *et al.* 1990). Earlier work had also shown that Lula could be stored for 60 days at 10 °C in 9% CO₂ + 1% O₂ or for 40 days at 7.2 °C in 10% CO₂ + 1% O₂ (Pantastico 1975). Spalding and Reeder (1972) showed that Lula can be stored for 8 weeks at 4–7 °C and 98–100% r.h. in 10% CO₂ + 2% O₂.

Mexican varieties

- 8 °C (Salunkhe and Desai 1984).

Pinkerton

- Guatemalan 227–397 g. It is very susceptible to grey pulp and both controlled atmosphere storage and modified atmosphere packaging delayed, but did not prevent, this postharvest disorder (Kruger and Truter 2003).

Pollock

- It is West Indian with fruit weighing up to 1.4 kg.
- 12.8 °C and 85–90% r.h. for 2 weeks (Lutz and Hardenburg 1968).

- 10–13 °C and 85–90% r.h. for 2 weeks for unripe fruits (Snowdon 1991).
- 13 °C and 85–90% r.h. for 2 weeks (Yahia 2011).

Subtropical grown fruit

- 7 °C and 90% r.h. for 2–4 weeks (Mercantilia 1989).

Taylor

- Guatemalan 340–510 g with 12–17% oil.
- 4.5 °C and 85–90% r.h. for 2–4 weeks for unripe fruits (Snowdon 1991).

Tropical grown fruit

- 13 °C (Mercantilia 1989).
- 20 °C and 60% r.h. for 2–7 days (Mercantilia 1989).
- 10 °C and 85–90% r.h. for 14–28 days (SeaLand 1991).
- 3–10% CO₂ with 2–5% O₂ (SeaLand 1991).

Waldrin

- West Indian, medium to large with 5–10% oil.
- 13 °C (Mercantilia 1989).
- 20 °C and 60% r.h. for 2–7 days (Mercantilia 1989).
- 10 °C and 85–90% r.h. for 14–28 days (SeaLand 1991).
- 10 °C and 3–10% CO₂ with 2–5% O₂ (SeaLand 1991).

West Indian fruit

- 12.8 °C and 85–90% r.h. for 2 weeks (Lutz and Hardenburg 1968).
- 15 °C for 2 weeks for most West Indian cultivars (Thompson *et al.* 1971).
- 12.8 °C and 85–90% r.h. for 2 weeks with 6.3% loss (Pantastico 1975).
- 12.8–13 °C for up to 2 weeks (Yahia 2011).

Controlled atmosphere storage

High CO₂ treatment (20%) applied for 7 days continuously at the beginning of storage or for 1 day a week throughout the storage period at either 2 or 5 °C maintained fruit texture and delayed ripening compared to fruit stored throughout in air (Saucedo Veloz *et al.* (1991). Storage in total nitrogen or total CO₂ however caused irreversible injury to the fruit (Stahl and Cain 1940). Burden (1997) recommended 7–13 °C and 90–95% r.h. with 2–5% O₂ and 3–10%

CO₂ for 2–4 weeks. Fellows (1988) gave a general recommendation of a maximum of 5% CO₂ and a minimum of 3% O₂. In South Africa Van der Merwe (1996) recommended 5.5 °C with 10% CO₂ with 2% O₂ for up to 4 weeks. In Australian Anonymous (1998) recommended 2–5% O₂ + 3–10% CO₂ at 12 °C. In other work 3–10% CO₂ + 2–5% O₂ was recommended for both Californian (*sic*) and tropical avocados (SeaLand 1991). 5 °C and 85% r.h. in 9% CO₂ + 2% O₂ was a general recommendation by Lawton (1996). Typical storage conditions were given as 10–13 °C in 3–10% CO₂ + 2–5% O₂ by Bishop (1996). A general comment was that storage at 5–13 °C in 3–10% CO₂ + 2–5% O₂ had a good effect and was of some commercial use (Kader 1985, 1992) and that the benefits of reduced O₂ and increased CO₂ were good. He reported that if the CO₂ level is too high, skin browning can occur and off-flavour can develop, and if O₂ levels are too low, internal flesh browning and off-flavour can occur. In experiments described by Meir *et al.* (1993) at 5 °C, increasing CO₂ levels over the range of 0.5, 1, 3 or 8% and O₂ levels of 3 or 21% slowed fruit softening, inhibited peel colour change and reduced the incidence of chilling injury. The most effective CO₂ concentration was 8% with either 3 or 21% O₂. They found that in 3% O₂ + 8% CO₂ fruits could be stored for 9 weeks, and after controlled atmosphere storage the fruits ripened normally and underwent typical peel colour changes. Some injury to the fruit peel was observed, probably attributable to low O₂ concentrations with peel damage seen in 10% of fruits held in 3% O₂ with either 3 or 8% CO₂ but it was reported to be too slight to affect their marketability.

Controlled atmosphere storage was reported to reduce chilling injury symptoms. There were less chilling injury symptoms in the cultivars Booth 8, Lula and Taylor in controlled atmosphere storage than in air (Haard and Salunkhe 1975, Pantastico 1975). Spalding and Reeder (1975) also showed that in storage 0% CO₂ + 2% O₂ or 10% CO₂ + 21% O₂ fruit had less chilling injury and less anthracnose (*Colletotrichum gloeosporioides*) during storage at 7 °C than fruits stored in air.

Intermittent exposure of crops to high levels of CO₂ may have beneficial effects. Marcellin and Chaves (1983) showed that exposing avocado fruit to 20% CO₂ for 2 days each week in storage at 12 °C delayed

their senescence and reduced decay compared to fruit stored for 7 days a week in air.

CA has been shown to affect the marketable life of fruits after they were removed from storage. Fruit were stored for 6 weeks at 5 °C in different CA conditions then ripened in air at 20 °C by Burdon *et al.* (2008). Those that had been stored in less than 3% O₂ + 0.5% CO₂ ripened in 4.6 days compared with 7.2 days for those that had been stored in 5% O₂ + 5% CO₂ and 4.8 days for fruit that had been stored in air.

Dynamic controlled atmosphere storage

Dynamic controlled atmosphere (DCA) storage was defined by Toivonen and DeEll (2001), DeLong *et al.* (2004), Burdon *et al.* (2008) and Lafer (2008) as where the gas mixture will constantly change owing to metabolic activity of the respiring fruits or vegetables in the store and leakage of gases through doors and walls. Where the O₂ level falls below a threshold level, several metabolic processes will change. These include ethanol synthesis and the chloroplasts will be stressed causing them to fluoresce. DCA uses the measurement of either chlorophyll fluorescence or ethanol production to control the O₂ level in the store. Burdon *et al.* (2008) concluded that avocado fruit quality was better after CA storage than after storage in air, and that DCA storage was better than 'standard' CA storage. The effect of DCA storage was to reduce the incidence of rots when ripe. Inclusion of CO₂ at 5% in CA retarded fruit ripening but stimulated rot expression and they concluded that it should not be used for CA storage of New Zealand grown Hass. DCA prolonged fruit storage life but when removed from storage they ripened more rapidly and more uniformly with fewer rots than those from 'conventional' CA storage (Burdon *et al.* 2009). They recommended setting the DCA O₂ level as soon as possible after harvest.

CA has been shown to affect the marketable life of fruits after they were removed from storage. Burdon *et al.* (2008) reported that after DCA storage, using chlorophyll fluorescence, Hass avocados ripened in 4.6 days at 20 °C after storage in compared with 7.2 days for 'standard' CA stored fruit and 4.8 days fruit stored throughout in air. They also stored Hass in DCA (less than 3% O₂ + 0.5% CO₂) for 6 weeks

at 5 °C and compared it to static CA in 5% O₂ + 5% CO₂. Chlorophyll fluorescence was also measured and found to occur in Hass which remained constant at 0.8 at 6 °C in O₂ levels down to 1% but below that it rapidly dropped to 0.68 within 24 h. When the fruit were kept for 6 days then returned to non-stressed atmosphere, the chlorophyll fluorescence rapidly returned to 0.8. At 6 °C CO₂ above 5% resulted in a slight reduction in chlorophyll fluorescence, which again returned to 0.8 when the fruit were returned to levels below 5%. The effect was more marked at 0 °C (Yearsley *et al.* 2003).

Earlier work showed that chlorophyll fluorescence changes of broccoli were associated with the accumulation of CO₂ in MA packages during storage (Toivonen and DeEll 2001). They also found that chlorophyll fluorescence was highly correlated with the anaerobic volatile content and off-odours in broccoli during longer storage durations in MA packaging.

Modified atmosphere packaging

Storage life was extended by 3–8 days at various temperatures by sealing individual fruit in PE film bags (Haard and Salunkhe 1975). Fuerte fruit sealed individually in 0.025-mm thick PE film bags for 23 days at 14–17 °C ripened normally on subsequent removal to higher temperatures (Aharoni *et al.* 1968). Levels of gases inside the bags after 23 days of storage were 8% CO₂ and 5% O₂ (Aharoni *et al.* 1968). Thompson *et al.* (1971) showed that sealing various seedling varieties of West Indian avocados in PE film bags greatly reduced fruit softening during storage at various temperatures (Table 15). Other recommendations included 5 °C in 30 µm thick PE film bags for Hass (Meir *et al.* 1997) or 4–7.5 °C in 50 µm thick PE bags for Fuerte (Scott and Chaplin 1978).

Table 15 Effects of storage temperature and wrapping treatment (31 µm thick polyethylene film bags compared to non-wrapped fruit) on the number of days to softening of avocados (source: Thompson *et al.* 1971)

	7 °C	13 °C	27 °C
Not wrapped	32	19	8
Sealed film bags	38	27	11

Ripening

Seymour and Tucker (1993) reported that avocado fruit do not normally ripen until they are harvested and can remain in a mature but unripe condition on the tree until picked. Changes during ripening include softening, starch breakdown and flavour development. Cellulase was involved in fruit softening during ripening of Hass (Kanellis and Kalaitzis 1992). Starch occurs in the plastids of unripe avocados at levels of about 12 mg g⁻¹ on a dry weight basis, but this reduced to undetectable levels in ripe fruit (Pesis *et al.* 1976). During the ripening of Fuerte the oil content remained constant (Eaks 1990).

Recommended ripening conditions were 18–21 °C with exposure to 10 µL L⁻¹ of ethylene for 24–72 h (Wills *et al.* 1989). Ripening fruit at lower temperatures, for example 15–20 °C, can lead to significant reduction in rots compared with higher temperatures (Hopkirk *et al.* 1994). Hatton *et al.* (1965) recommended 15.5 °C as the optimum temperature for ripening Florida avocados. In his review Yahia (2011) reported that 10–100 µL L⁻¹ of ethylene was used at 17–20 °C for 1–3 days, but optimum treatments times for the cultivar Hass in New Zealand were 2–3 days for early season fruits and 1–2 days for late season fruit.

Diseases

Diseases of avocado fruit that have been reported include:

- Alternaria rot, *Alternaria* sp.
- Anthracnose, *Colletotrichum gloeosporioides* (the conidial stage of *Glomerella cingulata* (Stonem.) Spauld & Schrenk).
- Bacterial soft rot, *Erwinia carotovora* Jones.
- Bacterial soft rot, *Pseudomonas syringae* pv *syringae* van Hall.
- Blue mould, *Penicillium expansum* Link.
- Botryodiplodia rot, *Botryodiplodia* sp. *Botryosphaeria obtusa* (Schwein.) Shoemaker *B. quercuum* (Schwein.) Sacc. *B. rhodina* (Cooke) Arx *Botrytis cinerea* Pers.:Fr. synonymous with *B. vulgaris* Link:Fr. *Botryotinia fuckeliana* (de Bary) Whetzel [teleomorph].
- Cercospora spot or blotch, *Pseudocercospora purpurea* (Cooke) Deighton
- Dothiorella rot, *Botryosphaeria ribis* Grossenb. & Duggar.

- Fusarium rot, *Fusarium* spp.
- Pestalotiopsis rot, *Pestalotiopsis versicolor* (Spreg.) Steyart.
- Phytophthora rot, *Phytophthora citricola* Sawada.
- Pink mould, pink rot, *Trichothecium roseum* Link. synonymous with *Cephalothecium roseum* Corda.
- Rhizopus rot, *Rhizopus stolonifer* (Ehrenb. Ex Fr.) Lind.
- Rusty blight *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz., *C. nigrum* Ellis & Halst.
- Scab., *Sphaceloma perseeae* Jenkins.
- Sooty blotch., *Akaropeltopsis* sp.
- Stem end rot, *Botryodiplodia theobromae* Pat.
- Stem end rot, *Dothiorella* spp.
- Stem end rot, *Thyronectria pseudotrichia* (Schw.) Seeler.

Colletotrichum, *Dothiorella*, *Alternaria* and *Phomopsis* spp. were isolated from decayed California avocados in order of frequency (Smilanick and Margosan 2001). The most prevalent fungi responsible for postharvest diseases in New Zealand were *Colletotrichum acutatum*, *C. gloeosporioides*, *Botryosphaeria parva*, *Botryosphaeria dothidea* and *Phomopsis* (Hartill 1991). *C. gloeosporioides* which causes anthracnose and a lenticular rot caused by *Dothiorella gregaria* can infect the fruit in the field and develop postharvest (Pantastico 1975). However, fungal infections were found to be associated only with area of primary damage, except where fruits were over ripe where the most common organism was *B. theobromae* (Thompson *et al.* 1971). Infections can also occur postharvest through the cut stalk (Pantastico 1975).

Bacillus spp. on their own or combined with a fungicide could be used to control postharvest diseases of avocados (Korsten *et al.* 1993). *Bacillus* spp. isolated from leaves and fruit of avocados were more effective in controlling anthracnose and stem end rot of avocados when applied as a postharvest dip than prochloraz applied in the same way. The combination of *B. subtilis* and prochloraz was more effective than when they were applied separately (Korsten *et al.* 1993), but postharvest chemical fungicide treatment is not permitted in some countries. Regnier *et al.* (2010) tested *Lippia scaberrima* essential oil and three of the major oil components, (d)-limonene, R-(–)-carvone, and 1,8-cineole, as well as that of S-(+)-carvone *in vitro* against *Colletotrichum*

gloeosporioides, *Lasiodiplodia theobromae* and an *Alternaria* isolate. They found significant inhibition of the mycelial growth of all the pathogens when applied at a concentration of 2000 µL L⁻¹. They subsequently carried out a simulated export trial using *L. scaberrima* essential oil, in addition to *Mentha spicata* (spearmint) essential oil and concluded that they could be alternatives to synthetic fungicides for the postharvest management of avocado fruit that would be acceptable to the organic market.

The cultivar Pinkerton is very susceptible to the postharvest physiological disorder called grey pulp and both CA storage and MA packaging delayed, but did not prevent it (Kruger and Truter 2003).

Bamboo shoots

Gramineae, Poaceae

Bambusa vulgaris Schrad. Ex Wendland. There are some 45 genera of bamboo mostly woody perennials including *B. oldhami* Munro and *Phyllostachys pubescens* (Carrière) J.Houz. *B. vulgaris* was reported to be the main bamboo species in cultivation and is not known in the wild, although its origin was probably Asia. Young shoots are widely used as a vegetable in some Asian countries especially China (Purseglove 1972). They are distributed throughout the tropics, subtropics and temperate regions. The edible parts are the thick shoots, called culms, which have just emerged from the soil in bamboo clumps and which, if left, would produce a new cane. They are soft and are boiled before eating. The culms may contain cyanogens that are toxic, but they are removed during boiling (Purseglove 1972). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 16.

Harvesting

The shoots are numerous among clumps of bamboo and usually harvested by cutting them off at ground level when they are 15–30 cm long and up to 7–8 cm in diameter at the base depending on the type. Bamboo is also grown for construction, pulp for paper and other purposes and harvesting young some of the young shoots would have little or no detrimental effects on its production.

Table 16 Chemical content of bamboo shoots in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	91.00 g	Thiamine	0.150 mg
Energy	27 kcal	Riboflavin	0.070 mg
Protein	2.60 g	Niacin	0.600 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.240 mg
Carbohydrate, by difference	5.20 g	Folate	7 µg_DFE
Total dietary fibre	2.2 g	Vitamin B-12	0.00 µg
Sugars, total	3.00 g	Vitamin A	1 µg_RAE
Calcium	13 mg	Vitamin A	20 IU
Iron	0.50 mg	Vitamin E	1.00 mg
		(α -tocopherol)	
Magnesium	3 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	59 mg	Vitamin D	0 IU
Potassium	533 mg	Vitamin K	0.0 µg
		(phyllquinone)	
Sodium	4 mg	Fatty acids, total saturated	0.069 g
Zinc	1.10 mg	Fatty acids, total monounsaturated	0.007 g
Total ascorbic acid	4.0 mg	Fatty acids, total polyunsaturated	0.134 g

Storage

Microbial decay appeared to be the primary cause of postharvest deterioration since bacterial, fungal and coliform microorganisms were present on external surfaces and internal tissues of shoots (Kleinhenz *et al.* 2000). Shoots stored at 5 °C and about 80% r.h. had a lower fibre content less discolouration of the cut ends and were of better quality than those stored at 30 °C and about 80% r.h. (Chen *et al.* 1989). At 8 °C discolouration and fungal growth restricted the shelf life of bamboo shoots to not more than 10 days (Kleinhenz *et al.* 2000). Ming Miao *et al.* (2012) exposed water bamboo shoots to high hydrostatic pressure for 10 min at room temperature of about 25 °C and then stored them at 4 °C for 7 days. They found that high hydrostatic pressure treatment extended their shelf life by delayed activities of PAL and pyrogallol peroxidase and retardation of lignin and cellulose accumulation compared to those that had not been treated. At 1–2 °C their respiration rate was about 0.7 µl CO₂ kg⁻¹ h⁻¹ (Kleinhenz *et al.* 2000).

Modified atmosphere packaging

Under traditional storage at ambient temperature of 20–25 °C without packaging, high transpirational weight loss limited shelf life to 1 day, but

packed in LDPE film, shelf life was extended to about 6 days (Kleinhenz *et al.* 2000). The shelf life of shoots in macro-perforated LDPE film bags, with 8.9% of the area perforated, was 17 days. In contrast, accumulation of condensate in low permeable materials, LDPE film bags, and particularly heat-sealed PVC film reduced shelf life to 21 and 14 days, respectively, owing to loss of visual quality. The most suitable film was 45 µm LDPE film bags with 0.01% micro-perforations and 10.5 µm thick non-perforated LDPE film. Storage in these bags reduced total weight loss of bamboo shoots to about 5% after 28 days. The micro-perforations minimized condensation within the bags and extended shelf life to at least 28 days (Kleinhenz *et al.* 2000). Huqing Yang *et al.* (2010) dipped peeled bamboo shoots for 1 h in 0.5 mM sodium nitroprusside, a nitric oxide donor, then packed them in 0.01 mm thick PE bags and stored them at 10 °C for 10 days. The sodium nitroprusside treatment delayed external browning, inhibited the synthesis of lignin and cellulose and delayed tissue lignification during storage. No information was given on the legislative implications of the treatment.

Beetroot

Chenopodiaceae

Beta vulgaris var. *conditiva*. It is also called red beet and is believed to have been derived from the wild subspecies *maritima*. Its wild form is believed to be a native of the sea shores of Europe, Africa and from Asia Minor to the East Indies. There are four types of *B. vulgaris*, which are beetroot, swiss chard where the leaves are eaten, sugar beet that is used for sugar extraction and fodder beet, such as mangel wurzel. Its cultivation dates back to the 17th century (Hedges and Lister 2006). The edible portion of beetroot is the swollen root, which is dark red in colour but can be white, golden or multicoloured. The major nutrients in beetroot are folate and potassium, though it also provides some vitamin C and iron and has high antioxidant activity. Ou *et al.* (2002) ranked beetroots among the 10 most potent antioxidant vegetables and were reported to be almost unique amongst vegetables in containing betalains, which comprise of betacyanins that are red to violet in colour and betaxanthins that are yellow. They are

Table 17 Chemical content of the swollen root of beetroot in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	87.58 g	Thiamine	0.031 mg
Energy	43 kcal	Riboflavin	0.040 mg
Protein	1.61 g	Niacin	0.334 mg
Total lipid (fat)	0.17 g	Vitamin B-6	0.067 mg
Carbohydrate, by difference	9.56 g	Folate	109 µg_DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 µg
Sugars, total	6.76 g	Vitamin A	2 µg_RAE
Calcium	16 mg	Vitamin A	33 IU
Iron	0.80 mg	Vitamin E (α-tocopherol)	0.04 mg
Magnesium	23 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	40 mg	Vitamin D	0 IU
Potassium	325 mg	Vitamin K (phyllloquinone)	0.2 µg
Sodium	78 mg	Fatty acids, total saturated	0.027 g
Zinc	0.35 mg	Fatty acids, total monounsaturated	0.032 g
Total ascorbic acid	4.9 mg	Fatty acids, total polyunsaturated	0.060 g

similar to anthocyanins but they never occur together in the same plant. The major betalain in beetroot is a betacyanin called betanin. Betalains are water soluble and are generally located in cell vacuoles, therefore beets lose their colour readily when cut as their colour pigments are contained in cell vacuoles that are easily ruptured if the cell is damaged (Stintzing and Carle 2004). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 17.

Postharvest physiology

Respiration rate, in watts per tonne, was 12–20 at 0 °C, 32–34 at 5 °C, 51–61 at 10 °C, 71–117 at 15 °C and 149–214 at 20 °C (SPLFS 2001). Uddin (1998) gave the respiration rates in mg CO₂ kg⁻¹ h⁻¹ as at 0 °C 4–6, at 5 °C 10–12, at 10 °C 16–20, at 15 °C 24–38 and at 20 °C 50–70. As would be expected, respiration rate was reduced when they were stored with their leaves removed and also in low O₂ compared to storage in air (Table 18).

Harvesting and handling

They should be harvested when they are a suitable size for the market, but while they are still young, tender

Table 18 Effects of temperature and reduced O₂ level on the respiration rate of beetroot in CO₂ production in milligrams per kilogram per hour (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
<i>Mature beetroot without leaves</i>					
In air	4	7	11	17	19
In 3% O ₂	6	–	7	–	10
<i>Bunched with leaves</i>					
In air	11	14	22	25	40
In 3% O ₂	7	–	14	–	32

and free from fibres. They are sometimes harvested and marketed while still immature with their tops still attached sometimes as early as 50–70 days after planting.

Forced air cooling with high humidity was the most suitable, hydrocooling was suitable, air cooling in a conventional cold store was less suitable and vacuum cooling was generally unsuitable (MAFF n.d.).

Storage

Fidler (1963) pointed out that in 1963 clamp or pit storage was often used over winter in temperate countries, but if the ambient temperature rose too high the beets might sprout. Schouten and Schaik (1980) recommended that the temperature in pits, clamps or cellars should not fall below –0.5 °C or exceed 5 °C to minimize losses caused by freezing, sprouting or rotting. Under these conditions they could be stored for 4–6 months. They also reported that large roots stored much better than small ones because they shrivelled more slowly. In England less rots were found on beets in storage at 4.4 or 2.2 °C than at 0 °C (Fidler 1963). Beets will freeze at about –2.9 to –2.7 °C (Wright 1942) or –1.67 to –1.06 for beet-roots and –0.94 to –0.39 for beet tops (Weichmann 1987), although SPLFS (2001) gave –0.9 °C for beets. Symptoms of chilling injury were a darker coloured flesh that oozes red droplets when cut; however, this seems more likely to be freezing injury. At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 1 week and SPLFS (2001) at about 20 °C for 7–8 days. Recommendations for refrigerated storage were:

- 0–1.7 °C and 79% r.h. (Wardlaw 1937).

- 0 °C and 90–95% r.h. for 1–3 months (Phillips and Armstrong 1967).
- 0–3.3 °C and 90–95% r.h. for 6–8 months (Shipway 1968).
- 0 °C and 95% r.h. for 3–5 months (Anonymous 1968, Hardenburg *et al.* 1990).
- 0–1.7 °C and 90–95% r.h. for 8–14 weeks with 33% loss (Pantastico 1975).
- 0 °C and greater than 98% r.h. for bunched beets for 10–14 days (Schouten and Schaik 1980).
- 1–2 °C and 98% r.h. for topped beets for 8–10 months (Schouten and Schaik 1980).
- 0 °C and 90–95% r.h. for 55–90 days for bunched beets (Tindall 1983).
- 4 °C and 95–98% r.h. for 6 months (Mercantilia 1989).
- 8 °C for 4 months (Mercantilia 1989).
- 12 °C for 2 months (Mercantilia 1989).
- 0 °C and 95–100% r.h. for 90–150 days (beetroot) (SeaLand 1991).
- 2.8 °C and 95–98% r.h. for 120–180 days (red beet) (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 3–8 months (Snowdon 1991).
- 0 °C and 90–95% r.h. for 10–14 days for bunched beets (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 2–3 weeks for bunched beets (Snowdon 1991).
- 0–1 °C and 95–100% r.h. for 120–180 days SPLFS (2001).

Controlled atmosphere storage

SPLFS (2001) recommended 5 °C and 5% O₂ with 5% CO₂ for fresh-cut beet, which had only a moderate effect. SeaLand (1991) reported that controlled atmosphere storage was said to have a slight to no effects and atmospheres containing over 5% CO₂ can damage the beetroot (Shipway 1968). This is partly confirmed by the findings of Robinson *et al.* (1975) who showed that at 0 °C the respiration rate was higher in low O₂ than in air (Table 19). However for beetroot that were stored with their leaves still attached, storage in low O₂ reduced their respiration rate. Beets can be stored for many months using refrigerated storage at 2 °C but some varieties have a very short marketable life. For example in Savoy beet, there was a decrease in the β -carotene, ascorbic acid and chlorophyll contents which was faster in summer, when the

Table 19 Storage of red beet in different systems over a 6-month period (source: adapted from Weichmann 1987)

Cooling system	Storage conditions	Plastic liners	Wastage (%)	Water loss (%)
Ambient air	2–12 °C, 90% r.h.	None	2.3	12.9
Ambient air	2–12 °C, 90% r.h.	Yes	0.7	2.7
Refrigeration	0–1 °C, 95% r.h.	None	2.3	6.3
Refrigeration	0–1 °C, 95% r.h.	Yes	3.5	0.9

shelf life was 4 days, than in winter, when it was 6 days (Negi and Roy 2000). Monzini and Gorini (1974) recommended 0 °C with 3% CO₂ and 10% O₂ for 1 month.

Modified atmosphere packaging

Sugar beet packed in PVC film maintained good appearance during 22 days of storage at an ambient temperature of 15–26 °C with a weight loss of 15.8% compared with 55% in the non-wrapped beets (Scalon *et al.* 2000). Storing of red beets in bulk bins lined with 0.125 mm thick polyethylene film was recommended by Shipway (1968) and in some cases using plastic liners in bins was actually better than refrigerated storage.

Diseases

The causes of storage rots include *Botrytis cinerea* Pers.: Fr. *Botryotinia fuckeliana* (de Bary) Whetzel [teleomorph], *Penicillium* spp. and *Phoma betae* A. B. Frank.

Bitter gourd

Cucurbitaceae

Momordica charantia L. Other common names include pepino, kerela, bitter melon, bitter cucumber and balsam pear. Purseglove (1972) reported that its origin is not known except that it was in the Old World and was taken to Brazil during the early slave trade, but is now widespread throughout the tropics. The pith of the fruit becomes sweet and intensely red as it ripens. It can be eaten uncooked in this state, and is a popular ingredient in some Southeast Asian salads. The rind is tough and bitter and removed before eating. The tender shoots and leaves are used



Figure 13 Bitter melon on sale in a supermarket in Los Angeles in the United States. See colour plate section.

as spinach and the seeds as a condiment. It has been used in African, Asian, Caribbean and southern European medicines for a variety of ailments, particularly digestive complaints and is reported to have some antimalarial activity.

It is a tropical and subtropical vine growing up to 5 m long that produces monoecious yellow flowers. The fruit is a pepo up to 25 cm long, which is ribbed with numerous tubercles (Figure 13) containing bitter flesh with many brown seeds up to 15 mm long with scarlet arils and a distinct warty exterior and an oblong shape. It has a relatively thin layer of flesh surrounding a central seed cavity filled with large, flat seeds and pith. The fruit is most often eaten green, or as it is beginning to turn yellow. At this stage, the fruit's flesh is crunchy and watery in texture. The skin is tender and edible. Seeds and pith appear white in unripe fruits; they are not intensely bitter and can be removed before cooking. As the fruit ripens, the skin becomes tougher, bitterer and too distasteful to eat. When the fruit is fully ripe, it turns orange and mushy, and splits into segments that curl back to expose seeds covered in bright red pulp. Harvesting is usually based on size and is some 15–20 days after flowering. The carotenoid content in the aril increased considerably during fruit ripening, lycopene being the main component, reaching 64.75 mg 100 g⁻¹ f.w. when fully ripe. Both chlorophylls a and b contents decreased significantly in the fruits stored at higher temperatures compared with those at lower temperatures (Tan *et al.* 1999). It also contains several bioactive glycosides and other terpenoid compounds, as well as cytotoxic proteins. The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 20.

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be some 3–5 days

Table 20 Chemical content of the pods of balsam pear, bitter melon (*M. charantia*) in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	94.03 g	Zinc	0.80 mg
Energy	17 kcal	Total ascorbic acid	84.0 mg
Protein	1.00 g	Thiamine	0.040 mg
Total lipid (fat)	0.17 g	Riboflavin	0.040 mg
Carbohydrate, by difference	3.70 g	Niacin	0.400 mg
Total dietary fibre	2.8 g	Vitamin B-6	0.043 mg
Calcium	19 mg	Folate	72 µg_DFE
Iron	0.43 mg	Vitamin B-12	0.00 µg
Magnesium	17 mg	Vitamin A	24 µg_RAE
Phosphorus	31 mg	Vitamin A	471 IU
Potassium	296 mg	Vitamin D (D2 + D3)	0.0 µg
Sodium	5 mg	Vitamin D	0 IU

(Mercantilia 1989). Refrigerated storage recommendations include:

- 0.6–1.7 °C and 85–90% r.h. for 4 weeks (Pantastico 1975).
- 1–2 °C and 85–90% r.h. for 20–30 days (Tindall 1983).
- 10 °C and 90% r.h. for 2–3 weeks (Mercantilia 1989).
- 11.7 °C and 85–90% r.h. for 14–21 days (SeaLand 1991).

Dong *et al.* (2005) reported that they could suffer from chilling injury, but when they immersed fruit in hot water at 42 °C for 5 min then packed them in PE film bags and stored them at 4 °C for 16 days, there were no symptoms of chilling injury. Susceptibility to chilling injury could explain the reasons for the storage recommendations of 10 and 11.7 °C, but Pantastico (1975), Tindall (1983) or Tan *et al.* (1999) did not mention chilling injury. Zong *et al.* (1995) reported experiments where fruits were harvested at horticultural maturity and stored for 2 weeks in various conditions. Fruit quality was similar after storage at 15 °C in 21, 5 or 2.5% O₂ + 0, 2.5, 5 or 10% CO₂ or in air. Fruits stored for 3 weeks in 2.5% O₂ + 2.5 or 5% CO₂ showed greater retention of green colour and had less decay and splitting than those stored in air.

In experiments the fruit harvested at horticultural maturity were packaged in polyethylene film bags and stored at 1, 10, 20 or 30 °C. The lutein and cryptoxanthin contents in the pulp increased during

storage at 20 and 30 °C, but increased only slightly at 1 °C and tended to decrease during storage and 10 °C. The pattern of changes of carotenoids in the aril was similar to that in the pulp (Tan *et al.* 1999).

Bitter yam

Dioscoreaceae

Dioscorea dumetorum (Kunth) Pax. Other common names include cluster yam, esuru, ikamba, ñame amargo, ono, three-leaved yam and trifoliate yam. This African species is closely related to the Asian species *D. hispida* Dennst. and is found wild throughout tropical Africa between 15° north and 15° south. It is cultivated in West Africa, especially in Nigeria (Coursey 1967, Purseglove 1972). Purseglove (1972) reported that in tropical Africa wild plants are widely eaten in times of food shortage. Nimenibo-Uadia (2003) reported that alkaloids present in the tuber extract provided some biochemical basis for their use in the management of patients with diabetes and confirmed its role as a traditional anti-diabetic remedy.

The twining stems are robust, hirsute and spiny with trifoliate with tomentose leaflets 12–16 cm long, 6–9 cm broad with pubescent and often spiny petioles. The flowers are small dioecious and fertile, produce oblong fruit some 4 cm long and 2 cm in diameter. The tubers may be single or (usually) produced in clusters: bulbils are rarely formed. The wild forms are often very poisonous, but the cultivated forms usually have little toxicity. Tubers are small and borne singly or in clusters that may be fused together. Harvesting is usually 8–10 months after planting and they are dug by hand. The wild forms are not edible and may be toxic. The flesh is variable in form and quality and their colour can vary from white to yellow (Kay 1987).

Composition

Opara (1999) reported that the tubers contained 67 g of water, 3.2 g of protein, 28 g of carbohydrate and 0.8 g of fibre per 100 g. The carbohydrate consists mainly of starch (Coursey 1967) and was 26.97% for yellow and 21.33% for white (Ojo and Ojo 2009). Kay (1987) gives a typical analysis of the edible portion of the tubers as; the composition were water 79%, protein 2.78%, fat 0.28%, carbohydrate 17%, fibre 0.3%,

ash 0.72%, calcium 92 mg 100g⁻¹ and ascorbic acid 6.6 mg 100g⁻¹. Alozie *et al.* (2009) found that the crude protein content of a wild variety was 11.37 g 100g⁻¹ and an 'edible' variety was 7.0 g 100g⁻¹. Ojo and Ojo (2009) found that the crude protein content was 8.24% for yellow and 5.44% for white varieties. However, after 6 weeks of storage in Nigerian ambient conditions this had fallen to 3.13% for yellow and 2.50% for white. The presence of important minerals such as iron, magnesium, phosphorus, calcium and zinc at high levels indicated that some useful application in the food and pharmaceutical industries could be found.

Toxicity

Many wild forms are often very poisonous but they are commonly used for pharmaceutical or medicinal purposes in Africa and Asia (Kay 1987). Cultivated varieties have been selected for low toxicity (Coursey 1967, Purseglove 1972). The toxic varieties have been shown to contain dihydrodiscorine isoclines, a heart stimulant and dioscorcoretine, a hypoglycemic agent (Bevan and Hirst 1958). The yellow ones are likely to contain the highly toxic alkaloid, which is a mixture of stereoisomers of dihydrodioscorine, but it can also occur in white fleshed tubers. Alozie *et al.* (2009) reported that tubers of both the edible and the wild varieties are processed by boiling and in the case of the wild variety, sliced, tied in a jute sack and left in a running water for 3 days to remove poisonous and/or bitter compounds. Coursey (1967) reported that tubers were sliced and soaked in frequent changes of water, usually with the addition of common salt. In West Africa soaked yams were prepared for consumption by flavouring with coconut and sugar. Other techniques reported from India, Solomon Islands and Madagascar involved boiling the yams before immersing in running water either whole, mashed or sliced. Wood ashes or tamarind were also sometimes added to the water for boiling in parts of India as an aid to the removal of acidity (Karnik 1969).

Storage

The dormancy period of *D. dumetorum* from Nigeria was 14–16 weeks (Opara 1999). Kay (1987) mentioned that tubers do not store well and become hard

and inedible some 4 weeks after harvesting. Afoakwa and Sefa-Dedeh (2002) also found that postharvest hardening occurred in *D. dumetorum* tubers, which was characterized by thickened cell walls and middle lamella in the cells. They found several treatments and storage methods that 'limited the contact of the tubers with the environment'. These were found to slow the hardening process. Drying sliced tubers is used as a method of storage. Ojo and Ojo (2009) reported that the crude protein content decreased during 6 weeks of storage in Nigerian ambient conditions. *D. dumetorum* stored under ambient and cold room conditions showed a rapid reduction in moisture and starch content and an increase in the total alcohol-soluble sugars and reducing sugars after 72 h of storage. The rate of decrease in moisture and starch and the rate of increase in the sugar level were higher in tubers stored at room temperature than those stored in cold storage (Passam *et al.* 1978). A similar trend was observed by Afoakwa and Sefa-Dedeh (2001) for the cultivar Jakiri after 110 days of storage found that starch content decreased by approximately 3.5–4.5 g 100 g⁻¹ while sugar and fibre levels increased.

Disease

Aspergillus niger and *Penicillium oxalicum* were the most common fungi on stored tubers with the optimum temperature for growth of 26–30 °C (Ogundana *et al.* 1970), but there was no growth observed on undamaged tubers.

Pests

Among the pests of stored yams the insects *Araecerus fasciculatus* and *Decadarchis minuscula* have been identified in Nigeria as infesting tubers of *D. dumetorum* (Plumbley and Rees 1983).

Bottle gourd

Cucurbitaceae

Lagenaria siceraria (Molina) Standl. It is synonymous with *L. vulgaris* Ser. and *L. leucantha* (Duch.) Rusby. Other common names include white-flowered gourd and calabash gourd. Purseglove (1972) reported that it has been common in both the Old World and New World from ancient times. It has been found

in horizons in Mexico dated 7000–5000 BCE and in Huaca Prieta, Peru dated 4000–3000 BCE. Remains have been found in an Egyptian tomb dating to 3500–3300 BCE and in China not later than the 1st century CE and New Zealand in the 12th century CE. It is an annual monoecious climbing herb with a longitudinal furrowed stem. The fruit is a pepo which can grow up to 1 m long, with a hard skin with edible or bitter flesh containing many white seeds, which can be up to 2 cm long. Chlorophyll content decreased during fruit development, but carotenoid content increased (Bhatnagar and Sharma 1994). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 21.

Fruit length and diameter increased continuously, but especially up to 28 and 20 days after anthesis, respectively in the cultivars Pusa Summer and Prolific Long, which were edible, tender and green from 12 to 24 days after anthesis (Bhatnagar and Sharma 1994). They had a shelf life of about 10 days at room temperature of 26–30 °C and 54–68% r.h. (Waskar *et al.* 1999). A refrigerated storage recommendation was 7.2 °C and 85–90% r.h. for 4–6 weeks with 3.2% loss (Pantastico 1975). Non-packed fruits of the cultivar Samrat could be stored for up to 18 days when packed in 25 µm thick PE bags with 2% vents. Fruits packed in polyethylene bags and stored in a cool chamber at 20.1–21.2 °C and 90–95% r.h. had a storage life of 28 days (Waskar *et al.* 1999).

Table 21 Chemical content of bottle gourd fruit (*Lagenaria siceraria*) in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	95.54 g	Total ascorbic acid	10.1 mg
Energy	14 kcal	Thiamine	0.029 mg
Protein	0.62 g	Riboflavin	0.022 mg
Total lipid (fat)	0.02 g	Niacin	0.320 mg
Carbohydrate, by difference	3.39 g	Vitamin B-6	0.040 mg
Total dietary fibre	0.5 g	Folate	6 µg_DFE
Calcium	26 mg	Vitamin B-12	0.00 µg
Iron	0.20 mg	Vitamin A	16 IU
Magnesium	11 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus, P	13 mg	Vitamin D	0 IU
Potassium	150 mg	Fatty acids, total saturated	0.002 g
Sodium	2 mg	Fatty acids, total monounsaturated	0.004 g
Zinc	0.70 mg	Fatty acids, total polyunsaturated	0.009 g

Breadfruit

Moraceae

Artocarpus altilis (Parkinson) Fosberg is synonymous with *A. communis* J.R. Forster & G. Forster, *Sitodiodium altile* Parkinson and *Radermachia incisa* Thunberg. Zerega *et al.* (2004) reported that *A. camansi* Blanco (breadnut or chataigne) and *A. mariannensis* (dugdug or chebiei) were close relatives of breadfruit. Breadfruit is also closely related to jackfruit (*A. heterophyllus*) and the African breadfruit (*Treculia africana*), which is grown in south-eastern Nigeria for its edible seeds (Nwaiwu *et al.* 1995). Breadnut produces seeds that have a flavour similar to chestnuts and some authorities reported that it is the same species as breadfruit (*A. altilis*). Most Melanesian and Polynesian breadfruit appear to have arisen over generations of vegetative propagation and selection from *A. camansi*, while most Micronesian breadfruit appear to be the result of hybridization between *A. camansi* and *A. mariannensis*. Breadfruit has been a component of traditional agroforestry systems and an important crop in the Pacific islands for more than 3000 years. It originated in the South Pacific and was spread throughout the numerous islands of Melanesia, Micronesia and Polynesia. It is a basic starch staple in the Pacific islands and transporting plants to the West Indies to feed the slaves, who were working in the sugar industry, was the reason for the voyage of HMS Bounty that ended in the famous mutiny.

The fruits are produced on large trees and are seedless syncarps that are globose to oblong in shape and up to 30 cm in diameter (Figure 14).

Composition

Fruits have a large starch content that is converted into sugars during ripening. Golden and Williams (2007) reported that the starch content was 15.5 g 100g⁻¹ and the sugars were 468 mg 100g⁻¹ arabinose, 415 mg 100g⁻¹ sucrose and 365 mg 100g⁻¹ glucose. Essential fatty acids detected at the highest concentration, which was in ripe fruit, were linoleic acid, an omega-6 fatty acid (0.15 mg g 100 g⁻¹), and linolenic acid, an omega-3 fatty acid (2.13 mg 100g⁻¹). They also contained amino acids including leucine (605 mg 100g⁻¹) and lysine (799 mg 100g⁻¹). Englberger *et al.* (2007) reported that ripe fresh seeded *A. mariannensis* contained up to 868 µg 100 g⁻¹ of β-carotene



Figure 14 Breadfruit on sale in an open market in Bedford in the United Kingdom in July 2009. See colour plate section.

and other carotenoids. Other breadfruits contained up to 750 µg 100 g⁻¹ lutein and total carotenoids up to 1260 µg 100 g⁻¹. Nutrient composition of breadfruit in 100 g⁻¹ f.w. was given by Dignan *et al.* (2004), Meilleur *et al.* (2004) and USDA (2012a) in Table 22.

Harvesting

In Jamaica they recognize two harvest maturities, which are referred to as *young* and *fit*. Young is characterized by their light green skin, almost complete absence of external latex and the fruit segments closely packed indicating that they are not fully grown. Fit is characterized by a darker green skin, with some browning and external dried latex and the segments not closely packed. Fit is preferred in Jamaica, and fit fruit are cooked by roasting or baking. Young fruit are cooked by boiling. In a comparison of harvesting methods Thompson *et al.* (1974c) found that the traditional method of detaching the fruit from the tree with a forked stick and allowing them to fall to the ground, then transporting them to the market in hessian sacks was satisfactory. In contrast New Guyana Marketing Corporation (2004) reported that breadfruit should never be knocked from the tree or dropped to the ground, as the resultant bruising will cause rapid softening and a significant reduction in market life. After detachment, the fruit should be carefully lowered to the ground and placed on a clean surface in a shaded area with the stem pointed outwards. The

Table 22 Chemical content of the fruit of breadfruit in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a; Dignan *et al.* 2004; Meilleur *et al.* 2004)

	Dignan <i>et al.</i> (2004)	Meilleur <i>et al.</i> (2004)	Nutrient Database (USDA 2012a)
Water (g)	72	67.6–79.4	70.65
Energy (kcal)	107	68–112	103
Protein (g)	1.5	0.8–1.4	1.07
Fat (g)	0.4	0.3	0.23
Carbohydrate (g)	23.6	17.5–29.2	27.12
Fibre (g)	2.5	0.8–0.9	4.9
Boron (mg)	–	0.50–0.54	11.00
Calcium (mg)	25	19.8–36	17
Iron (mg)	1	0.33–0.46	0.54
Magnesium (mg)	24	26.4–41.1	25
Phosphorus (mg)	–	26–29.7	30
Potassium (mg)	480	224–354	490
Sodium (mg)	1	4.2–10.4	2
Zinc (mg)	0.1	0.07–0.1	0.12
Manganese (mg)	–	0.04–0.07	–
Copper (mg)	–	0.06–0.1	–
Vitamin C (mg)	20	18.2–23.3	29.0
B1 Thiamine (mg)	0.1	0.25–0.31	0.110
B2 Riboflavin (mg)	0.06	0.09–0.11	0.030
B3 Niacin (mg)	1.2	1.6–1.8	0.900
Vitamin B-6 (mg)	–	–	0.100
β-Carotene (μg)	24	–	14
Vitamin B-12 (μg)	–	–	0.00
Vitamin E (mg)	–	–	0.10
Vitamin K (μg)	–	–	0.5
Fatty acids, total saturated	–	–	0.048 g
Fatty acids, total monounsaturated	–	–	0.034 g
Fatty acids, total polyunsaturated	–	–	0.066 g

stem should be re-cut with a sharp knife to a length of several centimetres. That is some of the fruit were damaged, but the ones that did not split had a similar quality to those that were caught and not allowed to hit the ground. They also reported that the fruit on a tree are of different physiological ages and do not reach maturity simultaneously. Therefore, harvesting involves climbing the tree and/or using a long pruning pole, where the fruit is cut and caught by hand or in a net, before hitting the ground. Where the fruit can be reached, they should be harvested by snapping the stem of the fruit off the tree at the point adjacent to the branch and not the fruit. Latex typically exudes

from stems cut too short and can result in brown staining of the skin. Stem length should generally be between 5 and 12.5 cm. When the stem is cut too short, it should be allowed to drain before putting the fruit in the harvest container. Care must also be taken to avoid damage to the fruit surface during harvest. Latex exudes from damaged tissue and causes staining. The cut stem should be oriented downward to prevent latex exudation onto the fruit surface and subsequent brown staining of the skin. The latex flow will soon cease and the fruit should be graded in the field to remove decayed, damaged, undersized, over-ripe or stemless fruit. Ragone (2011) reported that common tools for harvesting are a long picking pole with a forked end to clasp the stem or a woven or mesh bag to catch the fruit. Tripod orchard ladders were very practical, as the tripod design allowed them to be safely used on uneven or rough terrain.

Chemical treatments

Postharvest treatment with 100 nl L⁻¹ 1-MCP for 12 h reduced their respiration rate, but 10, 20 and 50 nl L⁻¹ did not affect respiration rate or ethylene production. All the treatments tended to delay softening and improve shelf life. However, at the later stage of ripening, some fruitlets were abnormally hard, causing uneven mushy softening with light brown streaks (Paull *et al.* 2005). They also reported that fruit treated with 25 or 50 nl L⁻¹ 1-MCP followed by storage in perforated PE bags at 17 °C had a shelf life of 10–11 days compared to 4 days for those not treated with 1-MCP fruit and stored at the same temperature. The fruit treated with 1-MCP and not stored in PE bags also had a 4-day shelf life. Bernardin *et al.* (1994) found that their shelf life at 16 °C could be extended from 4 days to 9 days by immersing them in 2% calcium chloride solution for at least 3 h directly after harvesting. Semperfresh F, Nutri-Save, Sta-Fresh MP and chitosan coatings all delayed fruit softening slightly at both ambient temperature and 13 °C, however, they all resulted in unacceptable discolouration of the flesh and development of off-odours (Worrell *et al.* 2002). In contrast New Guyana Marketing Corporation (2004) recommended a thin coating of paraffin wax applied by rapidly dipping the fruit in a solution of liquid paraffin or rubbing the fruit in a carnauba wax if the market prefers a shinier surface.

Postharvest physiology

It is a climacteric fruit reaching a peak in respiration rate of $3 \text{ ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 20°C (Biale and Barcus 1970). Worrell *et al.* (2002) confirmed that they are climacteric and found that the preclimacteric respiration rate was $20\text{--}50 \text{ ml kg}^{-1} \text{ h}^{-1}$ with a peak rate at ambient temperature of $24\text{--}30^\circ\text{C}$ of $300 \text{ ml kg}^{-1} \text{ h}^{-1}$, but was one-fifth this value for fruit stored at 13°C and occurred 5–10 days later. Peak ethylene production was similarly delayed at 13°C , but was depressed eightfold. Early-maturing fruit had an ethylene production rate of $1.0\text{--}1.5 \mu\text{l kg}^{-1} \text{ h}^{-1}$ and $0.7\text{--}1.2 \mu\text{l kg}^{-1} \text{ h}^{-1}$ for late mature fruit and both maturities were sensitive to ethylene exposure, which led to rapid ripening (Worrell and Carrington 1994, 1997). Thompson (1972a, 1972b, 1972c) showed that they softened quickly after harvest, which coincided with a rapid increase in TSS that would indicate breakdown of starch to sugars (Figure 15).

Storage

It is used as a starch staple vegetable, so that as soon as it begins to ripen it becomes soft and starch is converted into sugar and it is unacceptable. In

tropical ambient conditions breadfruit had a very short storage life; at 26 or 28°C their storage life was only 2 or 3 days (Thompson *et al.* 1974c, Maharaj and Sankat 1990). Ragone (2011) found that fruit ripened in 1–3 days after harvest but their shelf life could be extended by careful harvesting and pre-cooling with chipped ice in the field and during transport. In certain rural areas of Jamaica it is the practice to store them underwater in ambient temperatures. It is believed to extend their storage life, which was confirmed by Thompson *et al.* (1974b) who found that they did not begin to soften until they had been stored 14 days at 28°C at which time they split, having absorbed too much water. Storage at either 2.5 or 7°C resulted in the skin of the fruit turning from green to a dull brown in 2 or 3 days. When these fruits were removed to a higher temperature they lost weight rapidly and softening occurred in small circular areas over the surface, increasing in number and size with time (Thompson *et al.* 1974c). Worrell *et al.* (2002) confirmed chilling injury during storage at 7°C . However, Marriott *et al.* (1979) reported that chilling injury symptoms began to develop within 7 days at 12°C . The symptoms were a brown scald-like discolouration of the skin, failure to fully soften,

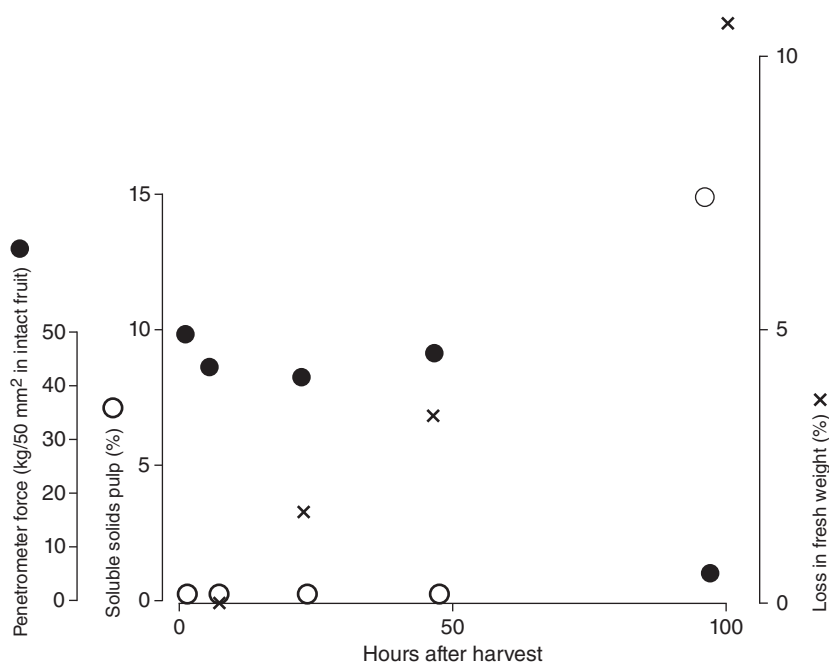


Figure 15 Postharvest changes in breadfruit stored in Jamaican ambient conditions.

poor flavour development and an increase in decay. Bernardin *et al.* (1994) claimed that browning of the peel was the limiting factor in storage. Refrigerated storage recommendations were:

- 12.5 °C and 92–98% r.h. for about 5 days (Thompson *et al.* 1974c).
- 13.3 °C and 85–90% r.h. for 14–40 days (SeaLand 1991).
- 13 °C and 95% r.h. for 1–3 weeks (Snowdon 1991).
- 13 °C for 10 days (Worrell *et al.* 2002).
- 15 °C for 10 days (Stice *et al.* 2007).

The optimum conditions for controlled atmosphere storage are given by Sankat and Maharaj (2007) as 5% O₂ + 5% CO₂ at 16 °C.

Modified atmosphere packaging

Storage in PE bags at 16 °C markedly reduced external skin browning, and there were still high chlorophyll levels after 10 days of storage. Shrink film wrapping also delayed changes in texture, TSS and starch content (Samsundar *et al.* 2000). Passam *et al.* (1981) recommended 14 °C for up to 10 days for the cultivar Whiteheart in PE film bags, but inclusion of potassium permanganate within the PE bag did not significantly improve storage. Storage of breadfruit at 12.5 °C sealed in 37.5 µm thick PE bags kept them in good condition for up to 13 days compared to 80% of the non-wrapped fruit being unmarketable after only 2 days (Thompson *et al.* 1974b). At 28 °C Maharaj and Sankat (1990) found that fruit could be stored for 5 days in sealed 25 µm thick PE film bags, while at 12 or 16 °C in sealed 25 µm thick PE film bags they could be stored for 14 days. Worrell and Carrington (1994) also showed that storing breadfruit sealed in plastic film bags maintained their green colour and fruit quality. They used 40 µm thick HDPE film or LDPE film and showed that fruit quality could be maintained in good condition for 2 weeks at 13 °C.

Transport

A shipment of breadfruit from Java at 3 °C was referred to by Wardlaw (1937), but there was no information on the time it took and their condition on arrival in Holland. In the 1970s commercial sea shipments were made in refrigerated containers from Jamaica to Britain at 13 °C taking some

10 days. The fruits were pre-cooled directly after harvest and packed individually in PE bags, then in 52 × 36 × 19 cm telescopic corrugated fibreboard cartons. They arrived in Britain in good condition. After a few commercial shipments the importer stopped the trade because the exporter found it difficult to ensure pre-cooling in Jamaica and fruits were often left unprotected while they waited for collection directly after they had been harvested. This meant many of the fruit were soft and ripe on arrival in Britain and therefore unmarketable. Trials were also carried out from Jamaica to Britain using airfreight. The fruit that were transported and stored without PE bags softened quickly and all were soft 4 days after arrival in Britain. The ones in PE bags began to soften 6 days after arrival and most were soft after 8 days but then some of the remainder took several days longer to soften (Figure 16). Research into the variation in softening of fruit in PE bags might indicate ways of prolonging their marketable life. In one of the trials pre-cooling before taking the fruit to the airport was studied. It was concluded that it was advantageous to harvest the day before taking them to the airport and placing each fruit in a PE bag and storing them at 12.5 °C compared to harvesting, packing and taking them directly to the airport (Thompson 1972b). For these airfreight trials the fruit were collected in a refrigerated truck and in one trial it broke down and the fruit were finally packed and delivered to the airport some 32 h after harvest. They arrived in the wholesale market in London 18 h later at which time about half of them were soft and unmarketable. In subsequent trials the fruit were kept under refrigeration for most of the 24 h between harvesting and delivery to the airport. They all arrived in a good marketable condition. There was a strong preference on the UK market for fruit that had been harvested at the fit stage of maturity.

Diseases

Postharvest diseases are rarely important in limiting their marketability. The principal postharvest fungal diseases causing fruit to decay were brown rot (*Phytophthora palmivora*), soft rot (*Rhizopus artocarp*) and pink rot (*Botryobasidium palmivora*). Brown rot was usually the most common and produced circular to oval-shaped brown lesions on the fruit surface (New Guyana Marketing Corporation 2004).

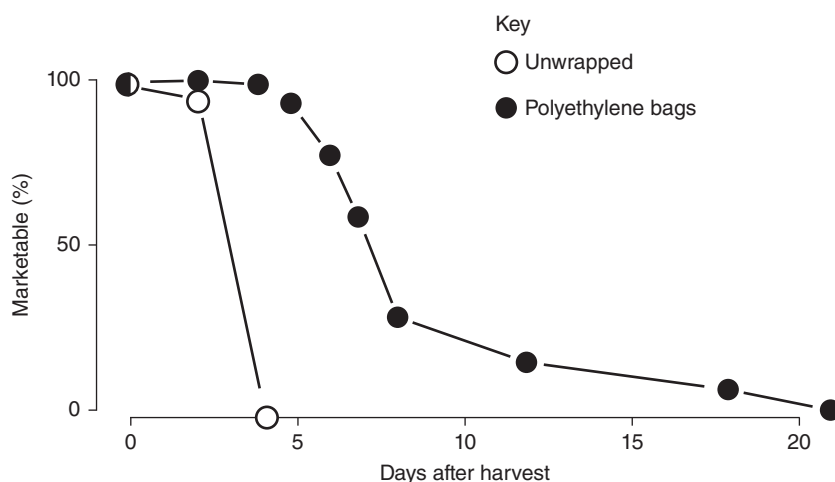


Figure 16 Marketable life of breadfruits stored individually in 37.5 µm thick polyethylene film bags or not in bags at 17 °C after airfreight from Jamaica to Britain.

Breadnut

Moraceae

Artocarpus camansi Blanco also called chataigne. Some authorities reported that it is the same species as breadfruit (*A. altilis*). The fruit are produced on tall trees that are up to 15 m tall with large lobed leaves and are similar in appearance to breadfruit trees (Figure 17). They are native to Southeast Asia and the Pacific Islands (Purseglove 1972). Breadnut produces seed that have a flavour similar to chestnuts and the pulp between the seeds can also be eaten. Negron de Bravo *et al.* (1983) gave the composition of the seeds and pulp in Table 23. The seeds are eaten raw or boiled and can be toasted and ground into a meal to make flatbread or a coffee-type beverage. ‘The fruit, boiled with salt-fish, pork, beef or pickle ... and has proved a wholesome and not unpleasant food [in times of scarcity]’ (Sturtevant 1892). USDA (2011b) reported that in the American tropics the ramón breadnut tree (*Brosimum alicastrum* Sw.), also a member of the Moraceae family, produces yellow fruit with single seeds.

Harvesting

Mohammed and Wickham (2011) worked on *A. camansi* and found that in Trinidad it took some 11–12 weeks from fruit set to full size, in which time the fruit had grown to well over 1 kg. They gave



Figure 17 Breadnut growing in Brazil.

harvest maturity as when the spacing between the spines on the surface of the fruit becomes slightly wider, which was 8–10 weeks after fruit set. They are harvested by breaking the pedicel at the point that it is attached to the branch. Care should be taken not to allow the fruit to fall to the ground as this can cause damage that affects their quality and postharvest life.

Table 23 Composition (%) of parts of breadnut fruit (*Artocarpus camansi*) (source: adapted from Negron de Bravo et al. 1983)

	Pulp	Seed
Moisture	56.0	20.0
Total carbohydrates	74.6	76.2
Starch	46.2	53.2
Protein	6.4	13.3
Fibre	18.0	2.5
Ash	1.8	3.7

Postharvest physiology

Mohammed and Wickham (2011) indicated that the fruit was climacteric. Changes during ripening included fruit becoming softer, pulp colour changing from white to bright yellow with concomitant increases in sugars and dry weight. Similar changes also occurred in the seeds.

Storage

Mohammed and Wickham (2011) recommended that optimum storage conditions were 10–12 °C and 85–90% r.h. Storage at 4–5 °C resulted in chilling injury whose symptoms appeared in 4 days. Symptoms were more severe when they were transferred to higher temperatures. Chilling injury symptoms were the skin and spines became dull green with water-soaked areas and subsequent browning of the skin, pulp and seeds. It also resulted in a detrimental flavour and increased susceptibility to secondary infections. Sealing individual fruit in LDPE or HDPE delayed the development of symptoms until 8 days at 4–5 °C.

Broad bean

Fabaceae, Leguminosae

Vicia faba L. synonymous with *Faba sativa* Moench. Other common names include fava bean, field bean, bell bean and Windsor beans. Kay (1979) reported that the taxonomy is confused. There are perhaps two major subspecies: *major* or *hortensis*, which has large flat seeds, is usually consumed by humans and *equina*, which has small, globular seeds and commonly called field bean or horse bean, is used for feeding livestock. Other studies have identified four subspecies of *V. faba*: *minor*, *equina*, *faba* and

pacifuga. Horse bean is sometimes recognized as *V. faba* var. *equina* Pers. Broad beans have been cultivated from ancient times. They originated in the Near East and the Mediterranean region and they are now cultivated throughout both tropical and temperate countries. It was the only bean known to Europeans until the common bean (*Phaseolus vulgaris*) was introduced from the New World. The edible portion is the flat pale green or white seeds that are borne in leathery pods, called legumes that turn blackish-brown as they mature, with a densely downy surface. Many modern cultivars have pods up to 25 cm long and 2–3 cm thick but wild plants bear smaller pods.

Broad beans are used in many dishes in the Mediterranean region, such as falafel. Fresh beans in season can be cooked and used as a vegetable. They are also dried to be used throughout the year. In Eritrea and Ethiopia they are mainly used as an alternative to peas to prepare shiro, which is a stew almost ubiquitous throughout the region. In Nepal they are eaten as a green vegetable when the pods are young, generally stir-fried with garlic. When mature they are dried and eaten roasted or mixed with other legumes. Raw broad beans contain the alkaloids convicine, isouramil and vicine that can cause the potentially fatal condition called favism in susceptible people.

Harvest maturity is between 90 and 220 days after sowing depending on the cultivar and growing conditions. They are commonly marketed still in their pods. Maturity is when the pods are well filled, but while they are still dark green in colour and 'snap'. They are harvested by hand and are usually picked two or three times from the same plant. They may also be allowed to mature fully to produce dry beans in which case they can be machine harvested.

Refrigerated storage recommendations include the following:

- 0–1 °C and 85–95% r.h. for 2–3 weeks (Anonymous 1967).
- 2–4 °C and 85–90% r.h. for 10–14 days (Lutz and Hardenburg 1968).
- 0–1 °C and 95–100% r.h. for 2–3 weeks (Snowdon 1991).

Although no specific information could be found on controlled atmosphere storage, Tomkins (1965) reported that there was a physiological disorders

Table 24 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of broad beans (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	35	52	87	120	145
In 3% O ₂	40		55		80

associated with high CO₂ that could result in pitting. However, it was found that low levels of O₂ generally resulted in a reduced respiration rate so controlled atmosphere storage may be useful (Table 24).

Broccoli

Brassicaceae, Cruciferae

Brassica oleracea var. *italica* Plenck or *B. oleracea* L. *Italica* Group. Other common names include calabrese, chou broccoli, sprouting broccoli, purple broccoli and brécoles. The edible portion is the terminal and axillary green heads and buds. It is similar to cauliflower except that it produces a loose terminal cluster of flower heads while in cauliflower a single head is produced. Sprouting broccoli with multiple flower heads became popular in the 18th century while calabrese with a single green main head was grown in Italy and introduced from there to the United States in the early part of the 20th century from where its cultivation has spread back to Europe and on to Japan (Dixon 2007). They will freeze at about -1.8 to -1.4 °C (Wright 1942) or -1.17 to -0.39 °C (Weichmann 1987). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 25. Total world production for broccoli and cauliflowers in 2010 was estimated by FAO (2012) as 19,794,339 tonnes.

Preharvest factors

The fertilizer application and irrigation have been shown to affect their quality and postharvest life. Broccoli, cultivated under normal (0.04 MPa, equivalent to field capacity) and low (0.40 MPa) soil water contents, was stored at either 1 °C or room temperature of 23 °C. Low soil water content and storage at 1 °C gave the best preservation of colour, antioxidant activity, L-ascorbic acid and

Table 25 Chemical content of broccoli with multiple flower heads in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.30 g	Thiamine	0.071 mg
Energy	34 kcal	Riboflavin	0.117 mg
Protein	2.82 g	Niacin	0.639 mg
Total lipid (fat)	0.37 g	Vitamin B-6	0.175 mg
Carbohydrate, by difference	6.64 g	Folate	63 µg_DFE
Total dietary fibre	2.6 g	Vitamin B-12	0.00 µg
Sugars, total	1.70 g	Vitamin A	31 µg_RAE
Calcium	47 mg	Vitamin A	623 IU
Iron	0.73 mg	Vitamin E (α-tocopherol)	0.78 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	66 mg	Vitamin D	0 IU
Potassium	316 mg	Vitamin K (phyloquinone)	101.6 µg
Sodium	33 mg	Fatty acids, total saturated	0.039 g
Zinc	0.41 mg	Fatty acids, total monounsaturated	0.011 g
Total ascorbic acid	89.2 mg	Fatty acids, total polyunsaturated	0.038 g

5-methyl-tetrahydrofolate contents. The phenolic compounds were reduced over time, independent of cultivation and storage conditions (Cogo *et al.* 2012). Ritenour (n.d.) reported that excessive application of nitrogen fertilizer can cause hollow stem in broccoli.

Harvesting and handling

Harvesting is just before the flower buds open. They are cut when they are 20–25 cm long with the axillary shoots cut at the same time (Pantastico 1975). If harvesting is delayed yellow flowers appear and they have a tough texture. Also they can have an unpleasant flavour if they are over developed. However, this is not likely to occur until heads are over mature and unmarketable (John Love, personal communication).

Brennan and Shewfelt (1989) reported that there were significant losses in marketable life of fresh broccoli if cooling was delayed by 3 h or more. Forced air cooling with high humidity was the most suitable pre-cooling method, vacuum cooling was also suitable and air cooling in a conventional cold store and hydrocooling were less suitable (MAFF n.d.). Top icing is also used but in that case it is important to have cartons that can withstand being wet without falling to pieces. Top icing was also commonly

carried out either directly after harvest in the field or after packing in the packhouse (Phillips and Armstrong 1967). After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of -1.7 to 0°C the broccoli temperature fell from 20 to 22.2°C down to 5.5°C (Barger 1963).

Prestorage factors

Irving and Joyce (2002) found that when sucrose was supplied immediately after harvest, through the floret transpiration system, yellowing was delayed. They also reported that postharvest treatment with the cytokinin 6-benzylaminopurine at $50\ \mu\text{L L}^{-1}$ retarded loss of chlorophyll. Skog and Chu (2001) evaluated the effect of ozone on the reduction of ethylene level in the storage atmosphere and storage life of broccoli florets. They were stored at $3 \pm 0.5^{\circ}\text{C}$ in ethylene levels of 1.5 and $2\ \mu\text{L L}^{-1}$, with or without ozone at $0.04\ \mu\text{L L}^{-1}$ and they found that floret opening was controlled better in the presence of ozone but the ozone appeared to result in cut surface browning. Ku and Wills (1999) showed that exposure to 1-MCP markedly extended the storage life of the cultivar Green Belt through a delay in the onset of yellowing during storage at both 5 and 20°C and in delayed development of rotting at 5°C . The beneficial effects at both temperatures were dependent upon concentration of 1-MCP and treatment time. Subsequently Gang Ma *et al.* (2009) also showed that 1-MCP treatment delayed the yellowing of broccoli florets and that exogenous ethylene exposure did not accelerate yellowing in the florets pre-treated with 1-MCP. Cefola *et al.* (2010) treated broccoli florets of the cultivar Raab with $1\ \mu\text{L L}^{-1}$ 1-MCP for 24 h at 20°C and then stored them at 5°C for 14 days in a humidified air flow and the same air flow containing $100\ \mu\text{L L}^{-1}$ of ethylene. Treatment with 1-MCP markedly extended the shelf life compared to those with no 1-MCP treatment, reduced postharvest deterioration, retarded chlorophyll degradation and delayed loss of visual quality especially in those exposed to ethylene. Broccoli florets were packed in perforated PE bags with or without ethanol pads and were continuously exposed to ethylene or not at 20°C in darkness. Ethylene exposure accelerated the yellowing of florets but this was inhibited by the ethanol pads (Toshiya Asoda *et al.* 2009). Ansorena *et al.* (2011) reported that coating broccoli with either chitosan or carboxy methyl

Table 26 Effects of temperature and reduced O_2 level on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{h}^{-1}$) of sprouting broccoli (source: adapted from Robinson *et al.* 1975)

Temperature ($^{\circ}\text{C}$)	0	5	10	15	20
In air	77	120	170	275	425
In 3% O_2	65		115		215

cellulose extended their postharvest life and reduced the rate of yellowing especially when combined with exposure to 50°C for $1\frac{1}{2}$ min before storage.

Postharvest physiology

Respiration rate was strongly affected by temperature (Table 26). SPLFS (2001) gave the respiration rate as 50–55 watts tonne $^{-1}$ at 0°C , 90–430 at 5°C , 237–443 at 10°C , 460–900 at 15°C , 740–900 at 20°C and 1480–2350 W tonne $^{-1}$ at 25°C . Respiration rate was affected by the O_2 level in the storage atmosphere, and the higher the storage temperature was, the greater was the effect of reduced O_2 (Table 26). This indicated that controlled atmosphere storage could be effective at the higher temperatures. The respiration rate of the cultivar Emperor decreased as the O_2 concentration of the atmosphere decreased even down to 0% over a 24-h period at 10 or 20°C (Praeger and Weichmann 2001). Kubo *et al.* (1989a and 1989b) reported that 60% CO_2 + 20% O_2 reduced their respiration rate. However, Makhoulouf *et al.* (1989) found that after 6 weeks of storage at 1°C in 10% CO_2 or more the respiration rate increased at the same time as the development of undesirable odours and physiological injury clearly indicating microbiological infection. Inaba *et al.* (1989) found that there was an increased respiration rate in response to ethylene at $100\ \mu\text{L L}^{-1}$ for 24 h at 20 – 35°C , but the effect was much reduced at lower temperatures.

Storage

Their shelf life in simulated room temperature of 20°C and 60% r.h. was shown to be only 1–2 days (Mercantilia 1989). After protracted storage the leaves discolour, the buds drop off and the tissue becomes soft. Refrigerated storage recommendations were:

- 0 °C and high humidity of about 90% r.h. (Wardlaw 1937).
- 0 °C and 95% r.h. for 7–10 days, with their shelf life reduced by half for every 5.5 °C rise in temperature (Tindall 1983).
- 0 °C and 90–95% r.h. for 7 days (Phillips and Armstrong 1967).
- 0 °C and 90% r.h. for 1–2 weeks (Mercantilia 1989).
- 0 °C and 95–100% r.h. for 10–14 days (Hardenburg *et al.* 1990).
- 0 °C and 90–95% r.h. for 10–14 days (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 1–2 weeks (Snowdon 1991).
- 0–1 °C and 95–100% r.h. for 35–50 days (SPLFS 2001).

Lijuan Zhan *et al.* (2012) studied the intensities of light exposure on the quality of fresh-cut broccoli during storage at various temperatures. They found that the combination of $24 \mu\text{mol m}^{-2} \text{s}^{-1}$ intensity light exposure and storage at 7 °C delayed sensory quality deterioration and preserved total chlorophyll content compared to storage in darkness.

Controlled atmosphere storage

Shelf life extension at 10 °C could be achieved with storage in 2–3% O₂ with 4–6% CO₂ (O'Beirne and Ballantyne 1987). Klieber and Wills (1991) reported that at 0 °C and 100% r.h. broccoli could be stored for about 8 weeks and their storage life could be further extended in less than 1% O₂ but storage in 6% CO₂ resulted in injury after 4–5 weeks. Cameron (2003) reported that low O₂ can retard yellowing at 5 °C but can also produce highly undesirable flavours and odours when O₂ falls below 0.25%. Lipton and Harris (1974) also reported physiological disorders associated with high CO₂ including accelerated softening and off-flavours. Other storage recommendations were:

- 0 °C and up to 10% CO₂ and 1% O₂ (Lipton and Harris 1974, McDonald 1985).
- 0–5 °C with 5–10% CO₂ and 1–2% O₂, which had a good effect but was of limited commercial use (Kader 1985, 1992).
- 0 °C in 2–3% O₂ + 4–6% CO₂ (Ballantyne *et al.* 1988).

- a maximum of 15% CO₂ and a minimum of 1% O₂ (Fellows 1988).
- 1.8–10% CO₂ + 2% O₂ for 3–4 weeks (Gorini 1988).
- 0–5 °C with 5–10% CO₂ and 1–2% O₂, which had a high level of effect (Saltveit 1989).
- 15 °C in 2% O₂ + 10% CO₂ (Saijo 1990).
- 0 °C with 5–10% CO₂ with 1–2% O₂ (SeaLand 1991).
- 0–5 °C in 5–10% CO₂ + 1–2% O₂ (Bishop 1996).
- 0 or 5 °C in 0.5% O₂ + 10% CO₂ or 10 °C in 1% O₂ + 10% CO₂ for Marathon (Izumi *et al.* 1996).
- 5–10% CO₂ + 1–2% O₂ (Jacobsson *et al.* 2004b).
- 3% O₂ + 2% CO₂ + 95% N₂ at 2 °C (Yang *et al.* 2004).
- 1–2 °C in less than 1% O₂ and 10% CO₂ for up to 25 days (Sirivatanapa 2006).

Generally controlled atmosphere storage reduced the rate of loss of chlorophyll and other phytochemicals. The cultivar Stolto was stored for 6 weeks at 1 °C in 0% CO₂ + 20% O₂, 10% CO₂ + 20% O₂, 6% CO₂ + 2.5% O₂, 10% CO₂ + 2.5% O₂ or 15% CO₂ + 2.5% O₂. Chlorophyll retention was better in controlled atmospheres than in air mainly due to increased CO₂ concentration (Makhlouf *et al.* 1989). Yang *et al.* (2004) also showed that losses of chlorophyll and ascorbic acid were reduced during CA storage compared to storage in air. The chlorophyll degradation was effectively delayed by storage at 0–1 °C in 5% O₂ + 10% CO₂ or in atmospheres with less than 1.5% O₂. Total carotenoid content remained almost constant during 8 weeks of storage in air or 0.5% CO₂ + 0.8–3.0% O₂, but increased in storage in 10% CO₂ + 3% O₂ (Yang and Henze 1988). Storage in 5 and 10% CO₂ + 3% O₂ were, by visual assessment, the most effective in reducing chlorophyll loss. Most controlled atmosphere combinations had no effect on flavour, but the samples stored at 10% CO₂ + 3% O₂ had an undesirable flavour after 8 weeks. CO₂ and O₂ levels had little effect on broccoli firmness (Yang and Henze 1987). However, colour and texture were not significantly influenced by controlled atmosphere storage compared to those stored at the same temperature in air (Berrang *et al.* 1990). Storage for 13 weeks in 15% O₂ + 6% CO₂ resulted in a modest retention of chlorophyll and a 30% reduction of trim loss as compared to those that had been stored in air. Storage of the cultivar Green Valient in 8% CO₂ + 10%

O₂, 6% CO₂ + 2% O₂ or 8% CO₂ + 1% O₂ reduced chlorophyll loss by 13, 9 and 32% and reduced trim loss by 40, 45 and 41%, respectively, and their respiration rate as compared to air (McDonald 1985). When freshly cut heads of the cultivars Commander and Green Duke were stored in air at 23 or 10 °C, the florets rapidly senesced. Chlorophyll levels declined by 80–90% within 4 days at 23 °C and within 10 days at 10 °C. Storage at 5 or 10 °C in 5% CO₂ + 3% O₂ at approximately 80% r.h. strongly inhibited loss of chlorophyll (Deschene *et al.* 1991). The effect of storage of the cultivars Marathon, Montop and Lord in either 2% O₂ + 6% CO₂ or 0.5–1% O₂ + 10% CO₂ on antioxidant activity was similar to those stored in air, but antioxidant activity and the vitamin C content increased in stored broccoli compared with fresh broccoli florets (Wold *et al.* 2006).

Controlled atmosphere storage generally reduced postharvest losses owing to disease but results have been mixed. Among the atmospheres tested by Makhoul *et al.* (1989), 6% CO₂ + 2.5% O₂ was the best for storage for 3 weeks since it delayed the development of soft rot and mould and there was no physiological injury. Compared with storage in air those in atmospheres containing 5–10% CO₂ + 3% O₂ had a small reduction in decay while storage in 0.8 and 1.5% O₂ resulted in more rapid decay (Yang and Henze 1987). Storage in 11% O₂ + 10% CO₂ at 4 °C significantly reduced the growth of microorganisms and extended the length of time they were subjectively considered acceptable for consumption (Berrang *et al.* 1990). The effects of controlled atmosphere storage on the survival and growth of *Aeromonas hydrophila* were examined. Two lots of each were inoculated with *A. hydrophila* 1653 or K144. A third lot served as an uninoculated control. Following inoculation they were stored at 4 or 15 °C in a CA storage system previously shown to extend their storage life or in ambient air. Without exception, controlled atmosphere storage lengthened the time they were considered acceptable for consumption. However, CA storage did not significantly affect populations of *A. hydrophila* (Berrang *et al.* 1989).

Other recommendations include 5–10% CO₂ + 1–2% O₂ (Jacobsson *et al.* 2004b), and 3% O₂ + 2% CO₂ + 95% N₂ at 2 °C (Yang *et al.* 2004). Yang *et al.* (2004) also showed that losses of chlorophyll and ascorbic acid were reduced during CA compared to

storage in air. The effect of storage of the cultivars Marathon, Montop and Lord in either 2% O₂ + 6% CO₂ or 0.5–1% O₂ + 10% CO₂ on antioxidant activity was similar to those stored in air, but antioxidant activity and the vitamin C content increased in stored broccoli compared with fresh broccoli florets (Wold *et al.* 2006). Storage of the cultivar 1997 in air retained glucosinolate between 4 and 7 days, while storage in 1.5% O₂ and 15% CO₂ showed a keeping quality of at least 14 days. They concluded that this indicated that CA storage preserved the nutritional quality of broccoli better than storage in air (Schouten *et al.* 2009).

Modified atmosphere packaging

Packaging in LDPE film or polybutadiene film retained their freshness in storage at 0 °C, but packaging with thicker film and subsequent storage at higher temperature there was induced the production of acetaldehyde, ethyl alcohol, and acetic acid, more so from stem tissues than from florets (Chachin *et al.* 1999). Mineral powders incorporated into films can be used for broccoli in order to control the O₂–CO₂ balance inside the bags (Industrial Material Research 1989, quoted by Abe 1990). Serrano *et al.* (2006) reported that non-wrapped broccoli lost weight, turned yellow and their stems hardened and there was a rapid decrease in total antioxidant activity, ascorbic acid and total phenolics giving a maximum storage period of only 5 days. These changes were delayed in modified atmosphere packaging especially in microperforated PP film and non-perforated PP film, with total antioxidant activity, ascorbic acid and total phenolic compounds remaining almost unchanged during the whole storage period of 28 days. Broccoli stored at 5 °C in 14% O₂ + 10% CO₂ or wrapped in PVC film for 3 weeks retained their market quality significantly better than those stored in air and left non-wrapped. Respiration rate of those in controlled atmosphere storage or in PVC film was reduced by 30–40% compared to the controls (Forney *et al.* 1989). Rai *et al.* (2008) studied various modified atmosphere packages in storage at 5 °C and 75% r.h. and found that perforated PP film (two holes, each of 0.3 mm diameter, with a film area of 0.1 m²) could be used to retain chlorophyll and ascorbic acid levels for 4 days. DeEll *et al.* (2006) reported that overall, the use of sorbitol, a water absorbent applied at greater than or equal to 2.5 g

with potassium permanganate in PD-961EZ bags at 0–1 °C for 29 days reduced the amount of volatiles that are responsible for off-odours and off-flavours. This was reported to maintain their quality and marketability longer. Acetaldehyde concentrations were higher in the bags with no sorbitol or potassium permanganate after 29 days, while ethanol was greater in both control bags and those with only potassium permanganate. After storage at 4 or 10 °C in LDPE film packages containing potassium permanganate with an equilibrium gas content of 5% O₂ + 7% CO₂, Jacobsson *et al.* (2004b) found that their sensory properties were better than those in other films and similar to freshly harvested broccoli. The optimum equilibrium atmosphere was found to be 1–2% O₂ and 5–10% CO₂. Jacobsson *et al.* (2004a) measured the gas inside various packages and found that storage in OPP resulted in the highest CO₂ concentration of 6%, while the lowest O₂ concentration of 9% was found in the LDPE package. They also found that broccoli stored in PVC film deteriorated faster than those packaged in the other films and the influence of all the plastic packaging tested was greater 10 °C than 4 °C.

Hypobaric storage

Broccoli was kept for 4 days at 1.1 °C then at 0 °C and 10 mm Hg or atmospheric pressure for 21 days. They were then assessed for quality after a shelf life at 10 °C. The ones that had been stored in atmospheric pressure had 60–90% yellowing and those that been in hypobaric storage had 40% yellowing with no off-odours or off-flavours (Burg 2004).

Brussels sprouts

Brassicaceae, Cruciferae

Brassica oleracea L. var. *gemmifera* Zenk. Forerunners of Brussels sprouts were likely cultivated in ancient Rome, but modern ones were grown possibly as early as the 13th century in what is now Belgium. The first written reference was 1587. It is a temperate crop and does not grow well in the tropics. During the 16th century, they became popular in the southern Netherlands and subsequently spread throughout the cooler parts of northern Europe (Anonymous 2011). In Japan from the 1930s and subsequently throughout

the world early maturing and F₁ hybrids have been developed including cultivars where all the buds mature at the same time to facilitate mechanical harvesting.

The plant is a biennial with a simple erect stem up to 1 m high. The edible portion is the vegetative buds that are borne in the leaf axils of the rigid stem. Their freezing point range was given as –1.28 to –0.83 °C (Weichmann 1987), but Cantwell and Suslow (2012) found that they freeze at about –0.6 °C. Slight freezing damage on the outer leaves may result in small dark and translucent areas. Severe freezing damage resulted in the entire bud becoming dark and translucent and very soft after thawing.

Podsędek *et al.* (2006) showed that for cabbages, Savoy cabbage and Brussels sprouts the total phenolic compounds varied from 21 to 171 mg 100 g^{–1} and vitamin C from 18 to 129 mg 100 g^{–1}. Levels of carotenoids ranged from 0.009 to 1.16 mg 100 g^{–1}, while α -tocopherol levels from 0.008 to 0.82 mg 100 g^{–1}. Red cabbage and Brussels sprouts were the richest sources of dietary antioxidants and their content was the lowest in white cabbage. Podsędek *et al.* (2010) recommended steam cooking to minimize the loss of hydrophilic antioxidants, while boiling significantly reduced the content of vitamin C by up to 53% and phenolics by up to 64% in cooked Brussels sprouts. Bitterness varies among cultivars and is associated with high concentrations of the glucosinolates sinigrin and progoitrin (Cantwell and Suslow 2012). The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 27.

Harvesting and handling

Everaarts (2000) found that maturity of the sprouts and the time of harvest strongly influenced postharvest yellowing, but growing in different levels of nitrogen fertilizer generally had no effects. However, the exception was the application of 31 kg N ha^{–1} as calcium nitrate resulted in increased yellowing of large sprouts from an early harvest. Time from planting to harvest depends on climatic and weather conditions and cultivar but it is generally between 90 and 180 days (Anonymous 2011). Harvesting is carried out when the buds are mature and tight before splitting of the outer leaves. They can be harvested by pulling and twisting by hand or being cut with a sharp knife. Brussels sprout harvesters have been developed which

Table 27 Chemical content of Brussels sprouts in 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	86.00 g	Thiamine	0.139 mg
Energy	43 kcal	Riboflavin	0.090 mg
Protein	3.38 g	Niacin	0.745 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.219 mg
Carbohydrate, by difference	8.95 g	Folate	61 µg_DFE
Total dietary fibre	3.8 g	Vitamin B-12	0.00 µg
Sugars, total	2.20 g	Vitamin A	38 µg_RAE
Calcium	42 mg	Vitamin A	754 IU
Iron	1.40 mg	Vitamin E (α-tocopherol)	0.88 mg
Magnesium	23 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	69 mg	Vitamin D	0 IU
Potassium	389 mg	Vitamin K (phyloquinone)	177.0 µg
Sodium	25 mg	Fatty acids, total saturated	0.062 g
Zinc	0.42 mg	Fatty acids, total monounsaturated	0.023 g
Total ascorbic acid	85.0 mg	Fatty acids, total polyunsaturated	0.153 g

perform similar operations to pea viner; harvesting the whole plant and cutting the sprouts from the stems. Special processing cultivars have been bred where all the Brussels sprouts mature at exactly the same time so facilitating mechanical harvesting. Brussels sprouts may be stopped, by removing the terminal growing point, to ensure more uniform development (John Love 1994, personal communication, quoted by Thompson 1996). Forced air cooling with high humidity was the most acceptable method, vacuum cooling was suitable, air cooling in a conventional cold store and hydrocooling were less suitable (MAFF n.d.).

Curing

Curing appeared not to have any affect. Heat treatment of the sprouts with moist air at 40, 45, 50 or 55 °C for 0, 30, 60 or 90 min caused no significant effects in the rate of senescence or storage quality (Wang 2000).

Postharvest physiology

Exposure to ethylene can result in the rapid breakdown of chlorophyll (Richardson and Meheriuk

Table 28 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Brussels sprouts (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	17	30	50	75	90
In 3% O ₂	14		35		70

1982) and can also cause elongation of the internodes and leaf abscission. This growth can open up a tight Brussels sprouts giving an effect that the trade calls 'blown', which results in them having little commercial value. Ethylene production was low at 2.5 and 5 °C in all atmospheres, but at 7.5 °C it was 20–170% higher in air than in low O₂. Ethylene production virtually stopped during exposure to 1% O₂ + 10% CO₂, 2% O₂ + 10% CO₂ or 20% O₂ + 10% CO₂, but increased markedly when removed to air storage (Lipton and Mackey 1987). Cantwell and Suslow (2012) reported that ethylene production rates were slightly higher than those of other leaf vegetables, but were still low at less than 0.25 µl kg⁻¹ h⁻¹ at 2.5–5 °C. Rates were higher in those that showed any yellowing or had been removed from beneficial CA storage. Respiration rate was strongly affected by temperature, but also by the O₂ level in the storage atmosphere. The effect of reduced O₂ was similar over the storage temperature range studied (Table 28). The cultivars Lunette, Rampart and Valiant in storage in 0.5, 1, 2 or 4% O₂ had lower respiration rates relative to those in air, but rates were similar among the four low O₂ levels (Lipton and Mackey 1987).

Storage

Prolonged storage resulted in the loss of the bright green colour, yellowing of the leaves, wilting, discolouration of the cut stems and decay (Lutz and Hardenburg 1968, Shipway 1968). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 1 day (Mercantilia 1989). Refrigerated storage recommendations were:

- 0–1.1 °C (Wardlaw 1937).
- 0 °C and 90–95% r.h. for 3–4 weeks (Phillips and Armstrong 1967).
- 0–1 °C and 95% r.h. for 7 days (Shipway 1968).
- 0 °C and 90–95% r.h. for 3–5 weeks (Lutz and Hardenburg 1968).

- 0–1.7 °C and 90–95% r.h. for 4–6 weeks (Pantastico 1975).
- –1 °C and 90–95% r.h. for 20 days (Mercantilia 1989).
- 0 °C for 14 days (Mercantilia 1989).
- 2 °C for 8 days (Mercantilia 1989).
- 4 °C for 5 days (Mercantilia 1989).
- 8 °C for 3 days (Mercantilia 1989).
- 0 °C and 95–100% r.h. for 3–5 weeks (Hardenburg *et al.* 1990).
- 0–1 °C and 95–100% r.h. for 3–5 weeks (Snowdon 1991).
- 0 °C and 90–95% r.h. for 21–35 days (SeaLand 1991).

Kasim and Kasim (2007) reported that exposure to light intensities of 1300 and 3500 lux, but particularly 1300 lux, reduced yellowing and senescence of the leaves of Brussels sprouts during storage at 5 °C and 85–90% r.h. and thus extended their storage life.

Controlled atmosphere storage

High quality Brussels sprouts could be maintained for 10 weeks in storage at 1.5–2.0 °C in air, which could be extended to 12 weeks in 5% CO₂ (Peters and Seidel 1987). Cantwell and Suslow (2012) found that they retained good appearance for 4 weeks at 2.5 °C, whether in controlled atmosphere storage or in air. They also found no benefits of controlled atmosphere storage at 0 °C. Other controlled atmosphere storage recommendations were as follows:

- 2.5, 5 or 7% CO₂ was found to be suitable by Pantastico (1975).
- 7% O₂ + 8% CO₂ for 80 days (Niedzielski 1984).
- 0–1 °C in 6% CO₂ + 15% O₂ or 6% CO₂ + 3% O₂ for up to 4 months (Damen 1985).
- 0–5 °C with 5–7% CO₂ and 1–2% O₂ which had a good effect on storage but was of no commercial use (Kader 1985, Saltveit 1989).
- 0–5 °C with 5–10% CO₂ and 1–2% O₂ which had an excellent potential benefit, but again limited commercial use (Kader 1989).
- 5–7.5% CO₂ and 2.5–5% O₂ helped to maintain quality at 5 or 10 °C, but at 0 °C with O₂ levels below 1% internal discolouration can occur (Hardenburg *et al.* 1990).
- 0 °C with 5–7% CO₂ and 1–2% O₂ (SeaLand 1991).

- 0–5 °C with 5–7% CO₂ and 1–2% O₂ (Bishop 1996).

Since low O₂ levels retarded yellowing and 10% CO₂ retarded decay development, the combination of low O₂ with high CO₂ effectively extended the storage life of Brussels sprouts at 5 and 7.5 °C. The beneficial effect of CA storage was still evident after return of the Brussels sprouts to air. Storage in 0.5% O₂ occasionally induced a reddish tan discolouration of the heart leaves and frequently an extremely bitter flavour in the non-green portion of the Brussels sprouts (Lipton and Mackey 1987). Cantwell and Suslow (2012) also reported that storage in less than 1% O₂ has been shown to cause extreme bitterness and may also cause internal discolouration, while 10–12% CO₂ could result in off-flavours and off-odours. The cultivar Rampart was stored either still attached to the stems or loose at 2–3 °C and less than 75% r.h. or 1 °C and less than 95% r.h. on the stem in air or 6% CO₂ + 3% O₂. Loose sprouts became severely discoloured at the stalk end after only 1 week in air and after 2 weeks in CA storage. Those on the stem remained fresh in CA storage for 9 weeks at 2–3 °C and for 16 weeks at 1 °C (Pelleboer 1983).

Hypobaric storage

Burg (2004) recommended that storage in 10 mm Hg should be tested since it could prevent the growth of micro-organism that could result in postharvest diseases.

Modified atmosphere packaging

Lutz and Hardenburg (1968) recommended packaging in plastic film to reduce moisture loss. Storage in PVC film at 0 °C for 42 days resulted in reduced browning of cut areas and reduced losses in weight and firmness compared with those that were not wrapped. Ascorbic acid and total flavonoid contents remained almost constant in the PVC wrapped Brussels sprouts while radical scavenging activity increased (Vina *et al.* 2007).

Disease

Brussels sprouts are not very prone to postharvest decay, but may be affected by the same organisms that infect other *Brassica* vegetables. Bacterial decay

due to various soft-rot-causing organisms, including *Erwinia* and *Pseudomonas*, may infect sprouts, but bacterial decay is usually associated with physical injury (Cantwell and Suslow 2012).

Buloy

Dioscoreaceae

Dioscorea divaricata Blanco. is synonymous with *D. oppositifolia* L., *D. foxworthyi* Prain & Burkill, *D. oxyphylla* R. Knuth, and *D. soror* Prain & Burkill. It was reported to grow wild and to be eaten by the Magbukún Ayta community in the Philippines.

Burdock

Asteraceae, Compositae

Arctium lappa L. synonymous with *A. majus* also called greater burdock, gobo and u-eong. Originating from the Siberian region of northern Asia it was used as a vegetable in Europe during the Middle Ages. It is particularly popular in Japanese cuisine and Chinese herbal medicine and was known from ancient times in China from where it was introduced in other Asian countries where it is cultivated and commonly consumed. It is a course herb up to 200 cm high, with globose pinkish purple flowers with the scales of the involucre each furnished with a hook called a burr. The leaves are dark green up to 71 cm long, coarse and ovate and are woolly underneath. The leafstalks are generally hollow and contact with the leaves and stems may cause dermatitis owing to the lactones they contain. The long taproot is the edible portion and is up to 0.9–1.2 m long and has a tapering width of 2.5 cm (Figure 18). The white flesh is crisp and sweet, with an earthy undertone. It is cultivated as a medicinal plant for its roots, young shoots and leaves that are also used in soups. It is often considered a weed in some countries including Britain and the United States, and Dandelion & Burdock is a soft drink that has long been popular in the United Kingdom, which has its origins in hedgerow mead commonly drunk in Britain during medieval times. Burdock roots were used as a bittering agent in beer before the widespread adoption of hops.

Burdock belongs to the same family of fuctan-containing plants that includes chicory (*Cichorium intybus*) and Jerusalem artichoke (*Helianthus*



Figure 18 Gobo on sale in California in the United States. See colour plate section.

tuberosus), which also have high fructans content. Burdock roots contain glucose, fructose, sucrose, fructooligosaccharides and inulin as the main carbohydrate reserve, with fructose the highest followed by sucrose, fructooligosaccharides and glucose (Ishiguro *et al.* 2010). Imahori *et al.* (2010) found that total fructooligosaccharides increased during 6 weeks of storage, however, this increase was much higher at 0 °C than that at 15 and 20 °C. Inulin content decreased during storage and final content was lower after storage at 20 °C. The fructose and glucose contents decreased significantly during storage at 1 °C, whereas the sucrose content increased sharply.

It is usually carefully harvested by hand to avoid damaging the root. Megumi Ishimaru *et al.* (2004) stored burdock roots in PE film bags and found that there was a significant decline in sugar content during storage at 8 and 20 °C. During storage for 30 days the fructan composition decreased to about 60% at 2 °C compared with storage at 8 or 20 °C where it decreased more to about 30%. Inulinase activity in roots stored at 2 °C was higher than in those stored at 8 and 20 °C.

Cabbage

Brassicaceae, Cruciferae

Brassica oleracea L. var. *capitata* L. Nieuwhof (1969) defined white headed cabbage as *B. oleracea* var. *capitata* forma *alba* DC, red cabbage as *B. oleracea* var. *capitata* forma *rubra* (L.) Thell and Savoy cabbage as *B. oleracea* var. *sabauda* L. The wild *B. oleracea* is probably native to the Mediterranean region of Europe or the coastal margins especially of France and Britain. It has been cultivated in Europe from at least Roman times, and from the 16th century Europeans cultivated cabbages in their colonies throughout the world (Dixon 2007).

The edible portion is the leaves and staminal bud, which is commonly called the heart. Some cultivars do not produce a heart, for example spring cabbage grown in Britain. Cabbages will freeze at about -0.5 to -0.4°C (Wright 1942) or -1.22 to -0.17°C (Weichmann 1987). Hounsom *et al.* (2009) reported that the antioxidant compounds identified in cabbage included ascorbic and dehydroascorbic acid, pyridoxine and pyridoxamine, nicotinamide and nicotinic acid, pantothenic acid and the flavonoids artemetin, betanidin, butein/naringenin chalcone, chalcone, cyanidin, equol, flavone, hydroxyflavone, kaempferol/luteolin, malvidin, naringenin/tetrahydrochalcone, nobiletin, pelargonidin, purpurogallin and quercitol, the phenolic acids benzoic, caffeic, cinnamic, coumaric/hydroxycinnamic, dimethoxybenzoic, gallic/trihydroxybenzoic, phenylacetic, rosmarinic, syringic, vanillic and veratric. Freshly harvested cabbages contained the highest levels of ascorbic acid and pyridoxine and a large variety of flavonoids but more than half of these compounds were lost during the first 5 months of commercial storage. However, after 6 months of storage an increase in the levels of some flavonoids was detected and the content of ascorbic acid, and vitamins B3 and B5 increased. The chemical content which was given by USDA Nutrient Database (2012a) is shown in Table 29. Total world production in 2010 was estimated by FAO (2012) as 66,397,587 tonnes for cabbages and other brassicas (*sic*).

Harvesting and handling

Harvest maturity for cultivars that produce hearts (headed cabbage) is when the heart is fully developed

Table 29 The composition of cabbages for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	White	Red	Savoy
Water (g)	92.18	90.39	91.00
Energy (kcal)	25	31	27
Protein (g)	1.28	1.43	2.00
Total lipid (fat) (g)	0.10	0.16	0.10
Carbohydrate, by difference (g)	5.80	7.37	6.10
Total dietary fibre (g)	2.5	2.1	3.1
Sugars, total (g)	3.20	3.83	2.27
Calcium (mg)	40	45	35
Iron (mg)	0.47	0.80	0.40
Magnesium (mg)	12	16	28
Phosphorus (mg)	26	30	42
Potassium (mg)	170	243	230
Sodium (mg)	18	27	28
Zinc (mg)	0.18	0.22	0.27
Total ascorbic acid (mg)	36.6	57.0	31.0
Thiamine (mg)	0.061	0.064	0.070
Riboflavin (mg)	0.040	0.069	0.030
Niacin (mg)	0.234	0.418	0.300
Vitamin B-6 (mg)	0.124	0.209	0.190
Folate (μg _DFE)	43	18	80
Vitamin B-12 (μg)	0.00	0.00	0.00
Vitamin A (μg _RAE)	5	56	50
Vitamin A (IU)	98	1116	1000
Vitamin E (α -tocopherol) (mg)	0.15	0.11	0.17
Vitamin D (D2 + D3) (μg)	0.0	0.0	0.0
Vitamin D (IU)	0	0	0
Vitamin K (phylloquinone) (μg)	76.0	38.2	68.8
Fatty acids, total saturated (g)	0.034	0.021	0.013
Fatty acids, total monounsaturated (g)	0.017	0.012	0.007
Fatty acids, total polyunsaturated (g)	0.017	0.080	0.049

so that it feels firm and solid to the touch. They are harvested by cutting the stalk just below the bottom leaves with a sharp knife. The outer leaves are trimmed, usually removing 3–6, together with any diseased, damaged or necrotic leaves. Any heads that are soft, immature, diseased or damaged by caterpillars should be discarded at harvest. Mechanical aids to harvesting involve cutting the cabbages by hand and then placing them on a conveyor on a mobile packing station, in the same way as cauliflowers (Figure 19). The harvesting equipment is slowly



Figure 19 Details of the trailer used for field packing cauliflowers.

conveyed across the field (Holt and Sharp 1989). In many cases cabbages are harvested and taken to a packhouse for grading and packing. In a study of cabbage farms and packing sheds in Texas in the United States, *Listeria monocytogenes* was isolated from 26 of the 855 samples taken. Twenty of these isolates were obtained from the cabbages, three isolates were from water samples and the other three were from samples from packing shed surfaces (Prazak *et al.* 2002).

Postharvest physiology

Cabbage produces very little ethylene but exposure to concentrations as low as $1 \mu\text{L}^{-1}$ postharvest can increase respiration rate and accelerate senescence, leaf yellowing, wilting and abscission (Inaba *et al.* 1989). They also found that there was an increased respiration rate in response to ethylene at $100 \mu\text{L}^{-1}$ for 24 h at temperatures over the range of $20\text{--}35^\circ\text{C}$, but the effect was much reduced at lower temperatures. Respiration rate was strongly affected by storage temperature and to a lesser extent by the O_2 level in the atmosphere. Also the effect of reduced O_2 was similar throughout the storage temperature range studied (Table 30). In other work respiration rate was given as $2.7 \text{ mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ for freshly harvested head cabbage (Weichmann 1987).

Pre-cooling

Cabbages are not normally pre-cooled, but in an experiment with vacuum cooling after 25–30 min at $4.0\text{--}4.6 \text{ mm Hg}$ with a condenser temperature

Table 30 Effects of temperature and reduced O_2 level on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{ h}^{-1}$) of Primo cabbage (source: adapted from Robinson *et al.* 1975)

Temperature ($^\circ\text{C}$)	0	5	10	15	20
In air	11	26	30	37	40
In 3% O_2	8	–	15	–	30

of -1.7 to 0°C the cabbage temperature fell from $20\text{--}22^\circ\text{C}$ to 7°C (Barger 1963). Forced air cooling with high humidity was the most acceptable method for head cabbage, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling less suitable. For leaf cabbage forced air cooling with high humidity and vacuum cooling were the most acceptable (MAFF n.d.).

Storage

Huang *et al.* (2002) reported that the factors that terminated storage were high weight loss and trim loss, inferior colour and freshness, loss of flavour and rotting at the cut end. They can be bulk stored for up to 3.5–4 metres deep (Shipway 1968). Their shelf life in simulated room temperature of 20°C and 60% r.h. was shown to be about 20 days for Savoy (Mercantilia 1989). Refrigerated storage recommendations were:

- 0°C for 3 months with 10% weight loss (Platenius *et al.* 1934).
- 0°C and 90–95% r.h. for 3–6 weeks for early cultivars or -1 to 2.2°C and 90% r.h. for others (Wardlaw 1937).
- 0°C for 2–4 months (Fidler 1963).
- 0°C and 85–90% r.h. for 2–6 months (Anonymous 1967).
- 0°C and 95% r.h. for up to 8 months with 1–1.5% weight loss per month and a total wastage including trimming of 20–25% (Shipway 1968).
- $1\text{--}2^\circ\text{C}$ and 90–95% r.h. for up to 7 months with 4.5% weight loss per month (Sohonen 1969).
- $0\text{--}1.7^\circ\text{C}$ and 92–95% r.h. for 4–6 weeks (wet season) or 12 weeks (dry season) with losses of 10% for the latter (Pantastico 1975).
- 0°C and 90–95% r.h. for 200 days (white) (Mercantilia 1989).
- 2°C for 100 days (Mercantilia 1989).
- 4°C for 75 days (Mercantilia 1989).
- 8°C for 50 days (Mercantilia 1989).

- -2°C and 90–95% r.h. for 120 days for Savoy (Mercantilia 1989).
- 0°C for 40 days for Savoy (Mercantilia 1989).
- 3°C for 20 days for Savoy (Mercantilia 1989).
- 20°C for about 5 days for Savoy (Mercantilia 1989).
- 0°C and 95–100% r.h. for 90–180 days (SeaLand 1991).
- $0-1^{\circ}\text{C}$ and 95–100% r.h. for 3 months (green) (Snowdon 1991).
- $0-1^{\circ}\text{C}$ and 95–100% r.h. for 6–7 months (white) (Snowdon 1991).

Controlled atmosphere storage

Cabbage is perhaps the most common vegetable to be stored commercially in CA conditions. Storage recommendations were:

- 0°C with 2.5–5% CO_2 and 5% O_2 for 5 months for Danish cultivars (Isenberg and Sayles 1969).
- 0°C in 3% CO_2 + 3% O_2 for Red and Savoy cabbages and 0–3% CO_2 + 3% O_2 for White cabbage (Stoll 1972).
- $0-5^{\circ}\text{C}$ with 5–7% CO_2 and 3–5% O_2 (Kader 1985).
- $0-5^{\circ}\text{C}$ with 3–6% CO_2 and 2–3% O_2 which had a high level of effect (Saltveit 1989).
- 0°C in 2.5–5% CO_2 with 2.5–5% O_2 at 0°C (Hardenburg *et al.* 1990).
- 5–7% CO_2 with 3–5% O_2 for Green, Red or Savoy (SeaLand 1991).
- $0-5^{\circ}\text{C}$ with 3–6% CO_2 and 2–3% O_2 which had a good effect and was of some commercial use for long-term storage of certain cultivars (Kader 1992).
- 0°C in 5% CO_2 + 3% O_2 for White cabbage (Bishop 1996).
- $0-1^{\circ}\text{C}$ with 2–6% O_2 (mostly at 3%) + 3–5% CO_2 (mostly at 5%) for 4 months compared to 2 months air for the cultivar Chu-chiu (Krala *et al.* 2007).
- $0-1^{\circ}\text{C}$ in 4% CO_2 + 3% O_2 that retained their quality and slowed down the degradation of vitamin C and chlorophyll compared to air storage of Savoy cultivars Owasa and Wirosa (Krala *et al.* 2007).

After storage of several white cabbage cultivars at $0-1^{\circ}\text{C}$ for 39 weeks the percentage recovery of marketable cabbage after trimming was 92% from those that had been stored in 5% CO_2 + 3% O_2 and

only 70% for those which had been stored in air (Geeson 1984). Cabbage stored for 159 days in air had a 39% total mass loss and in 3–4% CO_2 + 2–3% O_2 for 265 days the total mass loss was only 17%. The cabbage in CA storage showed better retention of green colour, fresh appearance and texture than those in air (Garipey *et al.* 1985). The cultivars Lennox and Bartolo were stored in air, 3% O_2 + 5% CO_2 or 2.5% O_2 + 3% CO_2 . Disease incidence was lower at both the controlled atmosphere storage conditions, and there were no trimming losses. Controlled atmosphere storage also helped to retain green colour in Lennox (Prange and Lidster 1991). Storage at $0.5-1.5^{\circ}\text{C}$ and 60–75% r.h. in 3% O_2 + 4.5–5% CO_2 lengthened the period for which cabbage can be stored by a least 2 months and improved quality compared to storage at $2-7^{\circ}\text{C}$ in 60–75% r.h. in air (Zanon and Schragl 1988).

Storage of the cultivar Tip Top at 5°C in 5% CO_2 + 5% O_2 gave the slowest rate of deterioration and at 2.5°C a CO_2 concentration greater than 2.5% was detrimental. The cultivar Treasure Island had a longer storage life than Tip Top in all CO_2/O_2 combinations. At 2.5°C in 5% CO_2 + 20.5% O_2 , 97% of Treasure Island was saleable after 120 days (Schouten 1985). Garipey *et al.* (1984) showed that after storage at 3.5–5% CO_2 + 1.5–3% O_2 for 198 days they a total mass loss of 14%, compared to 40% for those stored in air, and better retention of colour, fresher appearance and firmer texture. The cultivar Winter Green was stored at 1.3°C in 5–6% CO_2 + 2–3% O_2 + 92% N_2 and traces of other gases for 32 weeks compared to storage in air at 0.3°C . The average trimming losses were less than 10% for the CA stored cabbage, while those in air exceeded 30% and CA stored cabbage retained their colour, flavour and texture better (Raghavan *et al.* 1984). Huang *et al.* (2002) stored the cultivar Chu-chiu at $0-1^{\circ}\text{C}$ in 2–6% O_2 (mostly at 3%) + 3–5% CO_2 (mostly at 5%) and found that the storage life was double to 4 months compared to those in air storage. The factors that terminated storage were high weight loss and trim loss, inferior colour and freshness, loss of flavour and rooting at the cut end. Two cultivars of Savoy cabbage Owasa and Wirosa were stored at $0-1^{\circ}\text{C}$ in 4% CO_2 + 3% O_2 + 93% N_2 which retained their quality and slowed down the degradation of vitamin C and chlorophyll pigments compared to air storage (Krala *et al.* 2007). The need for fresh air ventilation at regular intervals

to maintain ethylene concentrations at low levels was emphasized by Meinel *et al.* (1988).

Low O₂ in storage reduced yellowing and trimming losses and inhibited root growth (Saltveit 1997). However, Masters and Hicks (1990) and Menniti *et al.* (1997) reported injury in low O₂ storage. They found that in storage at 0 °C in 0.5, 1.0 or 1.5% O₂ there was no injury to the cabbage until about 2 months at 0.5%, 3 months at 1.0% and 6 months at 1.5%. Schouten *et al.* (1997) found that low O₂ injury did not occur in the cultivar Oxheart in storage in 100% nitrogen at 0–4 °C until after 35 days. Saltveit (1997) reported that elevated CO₂ reduced rotting and sprouting. Menniti *et al.* (1997) reported CO₂ injury after 2 months at 0 °C in 20% CO₂ and after 2½ months (Menniti *et al.* 1997) or 6 months in 10% CO₂ (Masters and Hicks 1990). Symptoms also include off-flavours and off-odours (Masters and Hicks 1990, Menniti *et al.* 1997, Schouten *et al.* 1997). Abscissic acid concentration increased during storage at 0 °C in air. This increase was reduced in a 1% O₂ atmosphere which was shown also to delay the yellowing of the outer laminae and maintained higher chlorophyll content (Wang and Ji 1989). Berard (1985) found that storage at 1 °C in 2.5% O₂ + 5% CO₂ considerably delayed degreening, and eliminated abscission and loss of dormancy during the first 122 days of storage compared to those stored in air.

There is strong evidence that controlled atmosphere storage can reduce some diseases. Storage at –0.5 to 0 °C in 5–8% CO₂ prevented the spread of *Botrytis cinerea*, and total storage losses were lower in CA storage than in air (Nuske and Muller 1984). Pendergrass and Isenberg (1974) also reported less disease, also mainly caused by *B. cinerea*, and better head colour was observed with storage in 5% CO₂ + 2.5% O₂ + 92.5% N₂ compared to those stored in air at 1 °C and 75, 85 or 100% r.h. Berard (1985) described experiments in which 25 cultivars were placed at 1 °C and 92% r.h. He found that those in 2.5% O₂ + 5% CO₂ usually had reduced or zero grey speck disease and reduced incidence and severity of vein streaking compared to those stored in air for up to 213 days but not in every case. Black midrib and necrotic spot were both absent at harvest but in comparison with storage in air those stored in 2.5% O₂ + 5% CO₂ had increased incidence of black midrib and it also favoured the development of inner head symptoms on susceptible cultivars. In CA the incidence

of necrotic spot in the core of the heads of cultivar Quick Green Storage was increased which was particularly evident in a season when senescence of cabbage was most rapid. Even though both disorders were initiated in the parenchyma cells, black midrib and necrotic spot had a distinct histological evolution and affected different cultivars under similar conditions of growth and storage (Berard *et al.* 1986).

Hypobaric storage

It was reported that white cabbages were successfully stored with apples at 0 °C and 60 mm Hg (McKeown and Loughheed 1981) presumably by limiting the effect of ethylene produced by the apples or removing the ethylene from the container before it could have an effect. Onoda *et al.* (1989) found that cabbages retained better appearance and had lower weight loss when stored in cycles between 100 and 300 mm Hg (with no humidification) than those stored at a constant atmospheric pressure.

Diseases

Grey mould (*Botrytis cinerea*) can be minimized by rapid pre-cooling to 0 °C and controlled atmosphere storage. Alternaria rot (*Alternaria* spp.) can infect a many cruciferous vegetables causing significant storage losses. *Alternaria* spp. can also be transmitted through infected seed and from infected, cruciferous residues so crop rotation is important in its control. Ring spot, bacterial rots, watery soft rot and tobacco mosaic virus can cause significant losses (Snowdon 1991). In Napa cabbage black speck or pepper spot symptoms have been observed to develop faster at 4 °C than at either 0 or 10 °C (Brecht *et al.* 1987). No pathogens have been consistently associated black speck, and it is likely to be caused by a combination of genetic and environmental factors and spraying the growing crop with manganese salts has been shown to reduce it (Snowdon 1991). Ethylene did not promote development of black speck, but storage in 10% CO₂ reduced its severity (Brecht *et al.* 1987). Krala *et al.* (2007) successfully stored two cultivars of Savoy cabbage, Owasa and Wiroso, at 0–1 °C in 4% CO₂ + 3% O₂ + 93% N₂. Tea tree essential oil was added to half of the cabbage before storage and they reported a reduction in the total number of microorganisms by two logarithmic units after 1–2 months of

storage. Stanley *et al.* (1994) compared three strains of *Pseudomonas fluorescens* on postharvest disease control in cabbages. They found that strains CL80 and CL82 reduced fungal spoilage significantly and control by strain CL82 was similar to that achieved by postharvest treatment with fungicides. In a commercial trial the strain CL42 showed better results than any of the other bacterial strains.

Pectobacterium carotovorum ssp. *carotovorum* (formerly *Erwinia carotovora* ssp. *carotovora*) has been found to be the most common bacterial pathogen associated with the soft rot. Infection is primarily both through pre-harvest and postharvest wounds. The disease proliferates rapidly resulting in the rapid tissue breakdown. There are no effective chemical controls available. Bhat *et al.* (2012) treated cabbage heads with 200 µg ml⁻¹ of the antibiotic ciprofloxacin and stored them in PE bags 30 ± 1 °C for 7 days. Those treated with the antibiotic had a rot intensity of 4.5% and those without the antibiotic had 77.8% owing to infection with *P. carotovorum* ssp. *carotovorum*. However, it is doubtful that permission would be granted for their commercial use.

Physiological disorders

These were reviewed by Shipway (1968) and included black speck is where there are minute dark spots throughout the head, often associated with the stomata. Internal tip burn is where the margins of inside leaves turn brown, but the outer leaves look normal. Necrotic spot is where there are oval sunken spots a few millimetres across often grouped around the midribs. Pepper spot is where tiny black spots occur on the areas between the veins, which can increase during storage. Physiological disorders associated with high CO₂ included internal browning (Isenberg and Sayles 1969).

Capsicums

Solanaceae

Taxonomy of the edible *Capsicum* is controversial and Purseglove (1972) concluded that the following were recognized *C. annum* L. var. *annum*, *C. baccatum* var. *pendulum* (Willd.) Eshbaugh (synonymous with *C. pendulum* Willd.), *C. chinense* Jacq., *C. frutescens* L. and Chillie *C. pubescens* Ruiz & Pav. However, he

also supported the view that there are only two main species of edible *Capsicum*, which are *C. annum* L. and *C. frutescens* L. although others have classified them into several varieties and species for example USDA (2012a)

- Bird chillie or cherry capsicum *C. frutescens* var. *baccatum* (L.) Irish. This is a perennial shrub with conical, pointed, erect fruit up to 3 cm long and usually red and very pungent.
- Cayenne pepper *C. annum* L. var. *annuum*.
- Cayenne pepper *C. annum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill.
- Cherry pepper *C. annum* L. var. *cerasiforme* (Miller) Irish. They produce red, yellow or purple globose firm fruits up to 2.5 cm in diameter and that are pungent.
- Chillie *C. annum* L. var. *acuminata* Fingerh. They are widely grown in India and produce wrinkled, linear-oblong fruit up to 5 cm long and pungent.
- Chillie *C. pendulum* Willd. They are grown in South America.
- Chillie *C. pubescens* Ruiz & Pav. They are grown in Central and South America.
- Cluster pepper *C. annum* L. var. *fasciculatum* (Sturt.) Irish. They produce long slender erect fruits that are about 7.5 cm long borne in clusters that are very pungent.
- Long pepper *C. annum* L. var. *longum* Sendt. They produce red or yellow fruit mostly drooping and tapering to the apex and 20–30 cm long. They are often mild.
- Sweet pepper *C. annum* L. var. *grossum* Sendt.
- Tabasco or cone pepper *C. annum* L. var. *conoides* (Miller) Irish. They produce erect conical fruit about 3 cm long and are very pungent.
- Wrinkled pepper *C. annum* L. var. *abbreviatum* Fingerh. They produce ovate wrinkled fruits up to 5 cm long.

Capsicum species are diploid, most having 24 chromosome number ($2n=24$), but Tong and Bosland (2003) indicated the chromosome number for non-pungent species is $n=13$.

The fruit is an indehiscent many seeded berry and is conical or globose in shape, inflated with a basal depression. They have a mild flavour and are green as they develop and change colour to various shades of red, orange or yellow as they mature. Green peppers will freeze at about -1.2 to -0.9 °C

Table 31 The composition of capsicum fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.89 g	Thiamine	0.057 mg
Energy	20 kcal	Riboflavin	0.028 mg
Protein	0.86 g	Niacin	0.480 mg
Total lipid (fat)	0.17 g	Vitamin B-6	0.224 mg
Carbohydrate, by difference	4.64 g	Folate	10 µg_DFE
Total dietary fibre	1.7 g	Vitamin B-12	0.00 µg
Sugars, total	2.40 g	Vitamin A	18 µg_RAE
Calcium	10 mg	Vitamin A	370 IU
Iron	0.34 mg	Vitamin E (α-tocopherol)	0.37 mg
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	20 mg	Vitamin D	0 IU
Potassium	175 mg	Vitamin K (phylloquinone)	7.4 µg
Sodium	3 mg	Fatty acids, total saturated	0.058 g
Zinc	0.13 mg	Fatty acids, total monounsaturated	0.008 g
Total ascorbic acid	80.4 mg	Fatty acids, total polyunsaturated	0.062 g

(Wright 1942) or -0.94 to -0.61 °C (Weichmann 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 31.

Harvesting

The increase in size as it is growing is frequently used to determine when it should be harvested, which may simply be related to the market requirement. Most fruit are still green at harvest and therefore not physiologically mature. However, fully mature fruit, those that are red or yellow, are also harvested and it was found that fruit of this maturity lost less weight during storage than green immature fruit (Lutz and Hardenburg 1968). Allowing fruits to mature fully before harvesting, that is leaving them longer on the plants, results in lower yields per plant.

Prestorage treatments

The cultivar Setubal red peppers were treated with 900 ppb 1-MCP for 24 h at 20 °C or left non-treated. They were then packed in perforated PP bags by Fernández-Trujillo, *et al.* (2009) and stored at either 20 or 8 °C for 4½ days, then 3 days at 20 °C and finally 4½ days in domestic refrigerator at 5.6 °C

to simulate retail distribution. 1-MCP prevented the increase in skin colour and ethylene production but it may have increased the fruit susceptibility to shrivelling and weight loss and, to a greater extent, pitting and grey mould. Cao *et al.* (2012) found that peppers that had been treated with 1-MCP at 1 µl L⁻¹ had higher levels of chlorophyll, protein and vitamin C and lower respiration rates and ethylene production with enhanced antioxidant enzyme activities and polyamine contents compared with those not treated after 10 days of storage at 20 °C.

Meng *et al.* (2012) found that fresh-cut green peppers treated with pressurized argon at 4 MPa for 1 h directly after harvest could be kept in good condition for 12 days at 4 °C and 90% r.h. They found that water mobility, loss of water, loss of ascorbic acid and loss of chlorophyll were greatly reduced by treatment. The treatment maintained the cell integrity by inhibiting an increase in malondialdehyde and membrane permeability compared to those not treated. Chitosan has been successfully used as a postharvest coating to reduce water loss and maintain quality of stored capsicums (El Ghaouth *et al.* 1991).

Postharvest physiology

They are classified as non-climacteric (Bosland and Votava 2000) and were reported to produce very low levels of ethylene of 0.1 µl kg⁻¹ h⁻¹ at 10 °C and 0.2 µl kg⁻¹ h⁻¹ at 20 °C (González-Aguilar 2002). Respiration rate is given in Table 32. Inaba *et al.* (1989) found that there was increased respiration rate in response to ethylene at 100 µl L⁻¹ for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Robinson *et al.* (1975) reported much higher respiration rates and also found that storage in low O₂ reduced the respiration rate and had more effect at the higher temperature than at 0 °C (Table 33).

Table 32 Respiration rate of capsicum fruit at different temperatures (source: adapted from González-Aguilar 2002)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
5	6.8–7.8
10	9.5–15.2
15	24.0–29.6
20	32.4–36.0

Table 33 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of green peppers (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	8	11	20	22	35
In 3% O ₂	9	–	14	–	17

Pre-cooling

Capsicums that were hydrocooled, which took about 10 min, had a higher incidence of rots during subsequent storage than those were not hydrocooled, even when chlorine was added to the water (Seymour *et al.* 1981). This was due to water being trapped between the fruit and the calyx. Forced-air cooling with high humidity was the most acceptable method, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling less suitable (MAFF n.d.).

Storage

A major factor that influences the storage life is weight loss that results in shrivelling and loss of their crisp texture. Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2 days (Mercantilia 1989). Chilling injury occurred in 5 days at 0 °C as surface pitting followed by decay which only became manifest when fruits were transferred to room temperatures (Phillips and Armstrong 1967). González-Aguilar (2002) reported that storage at 5 °C reduced water loss and ripening, but after 2 weeks chilling injury appeared. Chilling injury has also been reported to occur within a few hours after removal from at storage temperatures below 7.2 °C as pitting and surface discolouration near the calyx (Anonymous 1968). Red bell pepper fruits of the cultivar Maor that had been dipped in methyl jasmonate at 10 µM for 30 s then stored for 4–10 weeks at 2 °C had reduced severity of chilling injury symptoms and a lower percentage of injured fruits compared to those not treated (Meir *et al.* 1996). In spite of the clear evidence of chilling injury reported above several researches report storage recommendations at very low temperatures. It is difficult to justify these and it may be that the research did not include observations of the fruit after removal from storage. However, refrigerated storage recommendations include

- 10 °C and 16 days or 4.4 °C for 28 days or 0 °C for 40 days (Platenius *et al.* 1934);
- 0 °C and 90% r.h. for 32 days (Wardlaw 1937);
- 0 °C and 90–95% r.h. for 1–3 weeks (Wardlaw 1937);
- 7–10 °C and 85–90% r.h. for 8–10 days (1, Phillips and Armstrong 1967);
- 7.2–10 °C and 90–95% r.h. for 2–3 weeks (Lutz and Hardenburg 1968);
- 10 °C and 75% r.h. for 5–8 days with 1.9–2.2% loss (Heydendorff and Dobreanu 1972);
- 21 °C and 65% r.h. for 2 days with 1.4–2.2% loss (Heydendorff and Dobreanu 1972);
- 7.2 °C and 85–90% r.h. for 3–5 weeks with 7.1% loss (green) (Pantastico 1975);
- 5.6–7.2 °C and 90–95% r.h. for 2 weeks (ripe) (Pantastico 1975);
- 5–7 °C and 95% r.h. for up to 14 days (Tindall 1983);
- 0.5 °C and 97–98% r.h. for 40 weeks in an ice bank store (Geeson *et al.* 1988);
- 2–2.5 °C and 90–95% r.h. in a conventional refrigerated store for a few months before becoming flaccid (Geeson *et al.* 1983, 1988);
- 15 °C (Umiecka 1989);
- 8 °C and 90–95% r.h. for 14 days (Mercantilia 1989);
- 5 or 10 °C for 10 days (Mercantilia 1989);
- 4 or 14 °C for 6 days (Mercantilia 1989);
- 1 °C for 2 days (Mercantilia 1989);
- 7–13 °C and 90–95% r.h. for 2–3 weeks (Hardenburg *et al.* 1990);
- 7–10 °C and 95–100% r.h. for 1–2 weeks (Snowdon 1991);
- 10 °C and 90–95% r.h. for 12–18 days (SeaLand 1991);
- 7 °C and 90–95% r.h. for 2–3 weeks (González-Aguilar 2002).

Controlled atmosphere storage

Colour retention was greater in fruits stored in low O₂ atmospheres than those in air (Luo and Mikitel 1996). High levels of CO₂ could result in internal browning (Morris and Kader 1977). Storage of the cultivar Jupiter for 5 days at 20 °C in 1.5% O₂ + 98.5% N₂ resulted in post-storage respiratory rate suppression for about 55 h after transfer to air (Rahman *et al.* 1995). Rahman *et al.* (1993a, 1993b) had previously

shown a residual effect on respiration rate of storage for 24 h at 20 °C in 1.5, 5 or 10% O₂. The residual effect lasted for 24 h when they were transferred to air with 1.5% O₂ having the most effect. Extending the storage period in 1.5% O₂ to 72 h extended the residual effect from 24 to 48 h. California Wonder stored in low O₂ had lower internal ethylene contents than those in air and storage in 1% O₂ resulted in significantly lower internal CO₂ than fruits stored in 3, 5, 7 or 21% O₂ (Luo and Mikitzel 1996). Other recommendations include

- 8–12 °C in 0% CO₂ + 2 or 3–5% O₂ which had a slight to fair affect but was of limited commercial use (Kader 1985, 1992, Saltveit 1989).
- 0–3% CO₂ + 3–5% O₂ (SeaLand 1991).
- 8 °C and greater than 97% r.h. in 2% CO₂ + 4% O₂ (Otma 1989).
- 3–5% O₂ was shown to retard respiration but high CO₂ could reduce loss of green colour and also result in calyx discolouration (Hardenburg *et al.* 1990).
- 8.9 °C the storage life of California Wonder was 22 days in air and 38 days in 2–8% CO₂ + 4–8% O₂ (Pantastico 1975).
- 2–5% O₂ retarded ripening and respiration rate and had a slight benefit on quality (González-Aguilar 2002).
- 5–10 °C in 3% O₂ + 5% CO₂ was more beneficial for storage for 3–4 weeks (González-Aguilar 2002).
- 10 °C and 5% CO₂ can cause calyx discolouration, skin pitting, discolouration and softening (González-Aguilar 2002).

Polderdijk *et al.* (1993) studied the interaction of controlled atmosphere storage and humidity. Mazurka fruits were stored for 15 days at 8 °C in atmospheres containing 3% CO₂ + 3% O₂ or air at 85, 90, 95 or 100% r.h. Fruits were then stored for 7 days in air at 20 °C and 70% r.h. and the incidence of an unspecified decay during this period increased relative to the humidity increase during storage. Storage in 3% CO₂ + 3% O₂ reduced the incidence of post-storage decay compared with storage in air. Luo and Mikitzel (1996) also reported that controlled atmosphere storage could reduce decay. After 2 weeks of storage at 10 °C California Wonder had 33% decay in those stored in air but only 9% of those stored in 1% O₂ and this reduction in decay continued

throughout the 4 weeks of storage. Storage in 3 and 5% O₂ atmospheres slightly reduced decay for a short time while the incidence of decay in fruits stored in 7% O₂ was not significantly different to those stored in air.

Modified atmosphere packaging

Lutz and Hardenburg (1968) found that fruits in perforated polyethylene film bags in cold storage had double the storage life than those stored not in bags. Hughes *et al.* (1981) showed that those stored sealed in various plastic films had a higher percentage of marketable fruit than those stored in air (Table 34). Lee and Lee (1996) used LDPE film of 27 µm thickness for the preservation of a mixture of carrot, cucumber, garlic and green peppers. The steady-state atmosphere at 10 °C inside the bags was 5.5–5.7% CO₂ and 2.0–2.1% O₂. Pala *et al.* (1994) studied storage in sealed LDPE film of various thicknesses at 8 °C and 88–92% r.h. and found that non-wrapped peppers had a shelf life of 10 days compared to 29 days for those sealed in 70 µm LDPE film (Table 35). Also this method of packaging gave good retention of sensory characteristics. Nyanjage *et al.* (2005) showed that temperature was the major factor in determining the postharvest performance of the cultivar California Wonder. For packaging in open trays, non-perforated or perforated PE bags did not significantly affect colour retention during storage at 4, 6.5 or 17 °C, but fruit had a significantly higher incidence of disease. Perforated PE packaging produced the best overall results. In other work the marketable value of peppers stored for 4 weeks at 8 °C was highest for those in PE bags with 0.1% perforations and in non-perforated PE bags compared to non-packaged fruit (Kosson and Stepowska 2005). After 2 weeks of storage in non-perforated PE bags the atmosphere was about 5% O₂ + 5% CO₂ and with 0.0001% perforation about 18% O₂ + 5% CO₂. Water condensation on the inner surface of PE bags and the stored peppers occurred in bags with 0.0001, 0.001, 0.01 and 0% perforations but not in those with 0.1% perforations. Muhammad *et al.* (2005) found that there were no significant differences in ascorbic acid and fruit firmness between the different perforated MA packaging of the cultivars Keystone, NuMex R Naky and Santa Fe Grande. However, perforated MA packaging was shown to reduce water loss, maintain turgidity of fruits and

Table 34 Effects of controlled atmosphere storage, plastic film wraps and hypobaric storage on the mean percentage sound fruit after 20 days at 8.8 °C followed by 7 days at 20 °C (source: adapted from Hughes *et al.* 1981)

Storage		Sound fruit (%)
Air control		43
<i>Controlled atmosphere storage</i>		
CO ₂	O ₂	
0	2	42
3	2	39
6	2	21
9	2	29
<i>Plastic wrap</i>		
Sarenwrap		67
Vitafilm PWSS		57
Polyethylene Pe301		69
VF 71		63
<i>Hypobaric storage (mm Hg)</i>		
152		46
76		36
38		42

delay red colour and disease development at both 8 and 20 °C. MA packaging extended postharvest life for another 7 days at 8 °C and 10 days at 20 °C compared with non-packaged fruits held at these temperatures. Postharvest water loss and turgidity were similar for fruits stored in packages with and without 26 holes at 8 and 20 °C. The optimum MA packaging can be different for different cultivars. Amjad *et al.* (2009) stored the cultivars Wonder King and P-6 in various thicknesses of PE bags at 7, 14 and 21 °C. They found

that the optimum thickness for Wonder King was 21 µm at 7 °C for minimizing weight loss, while P-6 fruits stored in 15 µm had the lowest weight loss and their maximum storage life was 20 days. Ascorbic acid levels and total phenolics and carotenoids also varied among cultivars, temperature and thickness of PE.

Hypobaric storage

Hypobaric stored capsicums at 8.6–9.0 °C and 82–90% r.h. in 38, 76 or 150 mm Hg had a significantly higher weight loss during storage than those stored at normal pressure. However, all had similar levels of 'sound' fruits after 20 days within the range 60–72%. Hypobaric stored capsicums did not have an increased subsequent storage life compared to those stored in atmospheric pressure at the same temperature (Hughes *et al.* 1981) (Table 34). However, Burg (1975) found that capsicums could be kept for 7 weeks at 7.2 °C in hypobaric storage without the loss of colour or 'crispness'. Burg (2004) reported that in storage at 7.2 °C and 80 mm Hg were in excellent condition after 28 days while those stored in atmospheric pressure began to deteriorate after 16 days and were in poor condition after 21 days. Even after 46 days capsicums in hypobaric storage were considered to be marketable except for a trace of mould on the cut stem. It was concluded that decay was the limiting factor in hypobaric storage. Burg (2004) quoted Jamison (1980) that after 50 days 87, 80, 47 and 0% were saleable (*sic*) from 80, 40, 15 mm Hg and atmospheric pressure,

Table 35 Number of days during which green pepper fruit retained either good or acceptable quality during storage at 8 °C or 88–92% r.h. (source: adapted from Pala *et al.* 1994)

	Sensory score ^a					Storage time (days)	
	Days	A ^b	C ^c	T ^d	F ^e	Good quality	Acceptable quality
Before storage	0	9	9	9	9	—	—
Non-wrapped control	15	4.3	4.6	2.7	4.2	7	10
20 µm LDPE	22	5.7	5.5	5.7	5.3	10	22
30 µm LDPE	20	5.8	6.0	6.0	4.5	10	20
50 µm LDPE	20	6.0	5.0	6.0	5.0	15	20
70 µm LDPE	29	7.8	7.8	7.6	7.8	27	29
100 µm LDPE	27	5.5	5.6	5.7	5.5	10	27

^a1–9 where 1–3.9 = non-acceptable, 4–6.9 = acceptable and 7–9 = good.

^bAppearance.

^cColour.

^dTexture.

^eTaste and flavour.

respectively, in experiments in the Grumman Allied Industries laboratory. Bangerth (1973) stored the cultivar Neusiedler Ideal at 10–12 °C for 23 days and found that those in 75 mm Hg were firmer, greener and had slightly higher ascorbic acid content and lower ethylene production than those stored in atmospheric pressure.

Diseases

In a survey of nine capsicum crops over four seasons in the United Kingdom the major cause of wastage were soft rots caused by *Botrytis cinerea* and *Rhizoctonia carotae* (Geeson *et al.* 1983, 1988). Infection levels of *B. cinerea* were related to weight loss, that is, the fruit with a high weight loss were more susceptible (Tronsmo 1989). *B. cinerea* grows well at the recommended storage temperatures for capsicums and good field sanitation and prevention of wounds on the fruit help to reduce its incidence. Hot water treatment at 53–55 °C for 4 min can give effective control without causing fruit injury. Storage above 10 °C encouraged bacterial soft rots (Lutz and Hardenburg 1968) and they occurred on washed or hydrocooled peppers, where water sanitation was inadequate and when they were stored above 13 °C (González-Aguilar 2002). Hughes *et al.* (1981) had previously found that hydrocooling resulted in a higher incidence of rots during subsequent storage, even when chlorine was added to the water, because of water being trapped between the fruit and the calyx.

Physiological disorders

Physiological disorders associated with high CO₂ include internal browning (Morris and Kader 1977). Sunscald resulted in light coloured soft areas on the skin. The disorder may be latent and develop during storage or marketing as water-soaked areas eventually becoming dry and brown.

Carrots

Umbelliferae

Daucus carota L. subspecies *sativus* (Hoffm.) Thell. The original carrots were believed to have been purple and grew wild in the region that is now Afghanistan

about 5000 years ago. These purple carrots were depicted in ancient Egyptian temple drawings and, along with white varieties, were also known to the ancient Romans who used them both for medicine and for culinary purposes. There are also records of red and yellow carrots. The orange carrot was not known until the 16th century, when it was said to have been deliberately developed by Dutch growers to honour of the House of Orange (Hedges and Lister 2006). The definition for carrots and sweetpotatoes was changed in the European Union Jam and Similar Products Regulations. The regulation stated that from January 1991 carrots and sweetpotatoes are 'sometimes fruit and not vegetables'. The reason given for this was that in Portugal they may be used in the manufacture of jam and EU regulations specify that jams can only be made from real fruit. Carrots and sweetpotatoes had therefore to be classified as fruits when used for jam and as vegetables when used for other purposes.

The edible portion is the modified swollen taproot. The major phytochemicals in carrots are the carotenoids: α -carotene, β -carotene, β -cryptoxanthin, lutein and zeaxanthin. They contain some phenolic compounds but probably only at low levels (Vinson *et al.* 1998). The human body can convert α -carotene, β -carotene and β -cryptoxanthin into retinol or vitamin A. In plants, these pigments assist in the light-capturing process in photosynthesis and protect against damage from visible light. Carrots also contain polyacetylenes, of which falcarinol [(9Z)-heptadeca1,9-dien-4,6-diyn-3-ol] has been found to be among the most bioactive and therefore of particular importance in terms of human health (Zidorn *et al.* 2005). Storage can affect the nutritional value of carrots. Kidmose *et al.* (2004) found that the carotenoid content appeared to be stable in carrots that had been stored at 0 °C for 4 months. They suggested that 4 months was possibly not long enough for the enzyme responsible for carotenoid degradation to show an effect. Falcarinol content in carrots stored at 0 °C was relatively stable for 1 month, after which there was a steady decline. Hydrolysis of sucrose, which affects flavour and disease development, was lowest at 0 °C compared to higher temperatures (Hasselbrink 1927). Sikora and Miedzybrodzka (1989) reported that the initial content of vitamin C was 5.44 mg 100 g⁻¹ and losses during 6 months of storage were about 50%.

Table 36 The composition of carrots for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	88.29 g	Thiamine	0.066 mg
Energy	41 kcal	Riboflavin	0.058 mg
Protein	0.93 g	Niacin	0.983 mg
Total lipid (fat)	0.24 g	Vitamin B-6	0.138 mg
Carbohydrate, by difference	9.58 g	Folate	19 µg_DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 µg
Sugars, total	4.74 g	Vitamin A	835 µg_RAE
Calcium	33 mg	Vitamin A	16,706 IU
Iron	0.30 mg	Vitamin E (α-tocopherol)	0.66 mg
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	35 mg	Vitamin D	0 IU
Potassium	320 mg	Vitamin K (phylloquinone)	13.2 µg
Sodium	69 mg	Fatty acids, total saturated	0.037 g
Zinc	0.24 mg	Fatty acids, total monounsaturated	0.014 g
Total ascorbic acid	5.9 mg	Fatty acids, total polyunsaturated	0.117 g

Changes in the vitamin C content depended on the period of storage but not on the conditions of storage. The chemical content was given by USDA Nutrient Database (2012a) in Table 36. Total world production in 2010 was estimated by FAO (2012) as 33,719,934 tonnes for carrots and turnips.

Preharvest factors

Splitting during growth can affect postharvest losses. The incidence of damage in carrots was shown to be affected by the total amount of irrigation and the time when it was applied. Heavy irrigation during the first 90 days after sowing resulted in up to 20% growth splitting, while minimal irrigation for the first 120 days followed by heavy irrigation resulted in virtually no splitting with a better skin colour and finish and only a small reduction in yield (McGarry 1993). Carrots contain an antifreeze protein that improves storage performance. Carrots grown in temperatures of less than 6 °C accumulated higher levels of this protein and subsequently showed less electrolyte leakage from cells, slightly higher dry matter and less fungal infestation than carrots grown in warmer temperatures. However, levels also varied between

environments in which the carrots had been grown (Galindo *et al.* 2004, Kidmose *et al.* 2004).

Harvesting and handling

They are usually harvested when they reach a size that is acceptable to the market. In Britain they may be stored in the ground and harvested as required (Fidler 1963). Harvesting is by digging by hand, but commercially they are harvested by machines that undercut the roots, separate them from the soil and load them into trailers which transport them to packhouses for grading and washing or loading into stores.

Hydrocooling was the most suitable method of pre-cooling, forced-air cooling with high humidity was also suitable, air cooling in a conventional cold store was less suitable and vacuum cooling was generally unsuitable (MAFF n.d.). However, with carrots marketed with their tops attached, vacuum cooling was also suitable. After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of –1.7 to 0 °C the carrot tops temperature fell to 2 °C from 20 to 22.2 °C (Barger 1963). Holmes and Kemble (2009) recommended hydrocooling both for bunched carrots and for mature, topped carrots grown in the southern United States.

Curing

Little work has been reported on curing carrots. During repair, phloem parenchyma cells near wounded surfaces accumulated suberin and lignin. At 15 °C, all cells in the surface layer had become suberized within 2 days of wounding but lignification was slower, reaching a maximum after 7 days but the distribution was patchy. When fresh wounds were inoculated with *Fusarium culmorum*, *Botrytis cinerea* or *Mycosporium acerina*, patterns of lignification were not related in a simple way to pathogenicity. Only *M. acerina* was stimulatory and remained localized in the wound surface bounded by heavily lignified cells. If a 250 µm layer of tissue was removed from the surface of fresh or healed wounds its high impedance to *M. acerina* was substantially reduced by removal of antifungal substances. The authors concluded that the development of structural barriers was less important than the accumulation of antifungal substances in the resistance of healing wounds (Garrod *et al.* 1982).

Postharvest physiology

Carrots produce very low levels of ethylene and at 20 °C it was less than 0.1 $\mu\text{L kg}^{-1} \text{h}^{-1}$. However, ethylene in the storage atmosphere was shown to increase their respiration rate (Sarkar and Phan 1979). Their respiration rate was given in Tables 37 and 38. Inaba *et al.* (1989) found that there was an increased respiration rate in response to 100 $\mu\text{L L}^{-1}$ ethylene for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Carrots exposed to ethylene can produce isocoumarin (3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin) that gives them a bitter flavour (Chalutz *et al.* 1969, Fidler 1963). Isocoumarin content was shown to increase with increasing concentrations of ethylene over the range 0.5–50 $\mu\text{L L}^{-1}$. Exposure to 0.1 $\mu\text{L L}^{-1}$ ethylene for 30 days at 5 °C resulted in little isocoumarin production, whereas exposure to 0.5 $\mu\text{L L}^{-1}$ for 14 days resulted in over 20 mg 100 g⁻¹ in the skin (Lafuente *et al.* 1989). Kramer *et al.* (2012) stored three cultivars in the dark at 17 °C for 7 days in an airflow with and without 7–10 $\mu\text{L L}^{-1}$ ethylene. Their results strongly suggested that ethylene-induced bitterness primarily resulted from the accumulation of 6-methoxymellein accompanied by other phenolics, while terpenoid and polyacetylene levels did not substantially contribute to their bitterness.

Storage

Carrots used to be stored in field clamps in a similar way to potatoes (Fidler 1963, Lutz and Hardenburg

Table 37 Respiration rates of carrots in milligrams carbon dioxide per kilogram per hour (source: adapted from Hardenburg *et al.* 1986)

Temperature (°C)	Topped	Bunched
0	10–20	18–35
5	13–26	25–51
10	20–42	32–62
15	26–54	55–106
20	46–95	87–121

Table 38 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of carrots (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	13	17	19	24	33
In 3% O ₂	7		11		25

1968). Storage in bulk containers of 1/2 to 1 tonne capacity was recommended, but storage in bags can restrict the airflow passed the carrots and thus reduce their postharvest life (Shipway 1968). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 7 days for topped mature carrots (Mercantilia 1989). SPLFS (2001) found that their marketable life was 8 days at about 20 °C. They will freeze at about –1.4 to –1.3 °C (Wright 1942) or –1.83 to –1.39 °C (Weichmann 1987). Refrigerated storage recommendations include

Bunched Immature with Tops Attached

- 0 °C and 90–95% r.h. for 4 weeks with 25% loss (Pantastico 1975);
- 0 °C and 95% r.h. for 10–14 days (Anonymous 1968);
- 0 °C and 95–100% r.h. for 21 days with about 15% weight loss (Tindall 1983);
- 0 °C and 95–100% r.h. for 2 weeks (Hardenburg *et al.* 1990);
- 0–1 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1991);
- 0 °C and 95–100% r.h. for 2 weeks for bunched carrots grown in the southern United States (Holmes and Kemble 2009);

Topped Immature

- 0–1 °C and 95–100% r.h. for 4–6 weeks (Snowdon 1991).

Topped Mature

- 0–1.7 °C for 22 weeks with 7% weight loss (Hasselbrink 1927);
- 0 °C and over 90% r.h. for 5 months with 10% weight loss (Wardlaw 1937);
- 0–1.1 °C and 79% r.h. (Wardlaw 1937);
- 0 °C and 95% r.h. for 20–24 weeks with 20–35% loss (Pantastico 1975);
- –1 to 1 °C and 90–95% r.h. for 6–7 months (Shipway 1968);
- 0 °C and 90–95% r.h. for 4–5 months (Lutz and Hardenburg 1968);
- 0 °C and 95% r.h. for 4–5 months (Anonymous 1968);
- 0 °C and 95–100% r.h. for 100–150 days or longer with 20–35% weight loss (Tindall 1983);
- 0 °C and 90–95% r.h. for 180 days (Mercantilia 1989);

- 2 °C for 100 days (Mercantilia 1989);
- 8 °C for 50 days (Mercantilia 1989);
- 0–1 °C and 98–100% r.h. for 7–9 months (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 28–180 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 4–8 months (Snowdon 1991);
- 0 °C and 95–100% r.h. for 120–180 days (SPLFS 2001);
- 0 °C and 98–100% r.h. for 7–9 months for mature, topped carrots grown in the southern United States (Holmes and Kemble 2009).

Controlled atmosphere storage

Respiration rate was strongly affected not only by temperature but also by the O₂ level in the storage atmosphere (Table 39). The effect of reduced O₂ was similar at all the storage temperatures. Storage at 2 °C in 1–2% O₂ for 6 months was reported to have been successful (Platenius *et al.* 1934). However, increased decay was reported at 0 °C and 95% r.h. in atmospheres of 6% CO₂ + 3% O₂ compared to storage in air (Pantastico 1975). Also controlled atmosphere storage was not recommended by Hardenburg *et al.*

Table 39 The composition of cassava for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	59.68 g	Thiamine	0.087 mg
Energy	160 kcal	Riboflavin	0.048 mg
Protein	1.36 g	Niacin	0.854 mg
Total lipid (fat)	0.28 g	Vitamin B-6	0.088 mg
Carbohydrate, by difference	38.06 g	Folate	27 µg_DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Sugars, total	1.70 g	Vitamin A	1 µg_RAE
Calcium	16 mg	Vitamin A	13 IU
Iron	0.27 mg	Vitamin E (α-tocopherol)	0.19 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	27 mg	Vitamin D	0 IU
Potassium	271 mg	Vitamin K (phylloquinone)	1.9 µg
Sodium	14 mg	Fatty acids, total saturated	0.074 g
Zinc	0.34 mg	Fatty acids, total monounsaturated	0.075 g
Total ascorbic acid	20.6 mg	Fatty acids, total polyunsaturated	0.048 g

(1990) since carrots stored in 0–1 °C and 98–100% r.h. had more mould growth and rotting in 5–10% CO₂ + 2.5–6% O₂ than in air. Fidler (1963) found that high levels of CO₂ in the storage atmosphere could give the roots a bitter flavour, presumably by stimulating isocoumarin synthesis.

Modified atmosphere packaging

Gioppo *et al.* (2011) stored four cultivars of carrot either in polystyrene trays covered with PVC film or in bulk. After storage the PVC film covered carrots had an average of 14.7% with side roots and 5.4% rot while those in bulk had 75.5% with side roots and only 0.7% rot. Modified atmosphere packaging is used commercially to extend the marketable life of immature carrots. Seljasen *et al.* (2003) found that carrots being gently handled and stored in perforated plastic bags at low temperature retained the most favourable taste in the Norwegian distribution chain. Modified atmosphere packaging did not result in an increase in off-flavours or an increase in 6-methoxymellein, which has been associated with off-flavours, or in a reduction in sugars. Storage in PE bags at 0 °C was reported by Jitender *et al.* (1999) to slow the decrease in ascorbic acid concentration and reduce the levels of TSS and their weight loss to 1% over an 8-day period compared to carrots stored in gunny bags in ambient conditions which lost 16% in weight.

Hypobaric storage

In storage at 2 °C and 60 mm Hg containing apples, cabbages and carrots no isocoumarin was detected in the carrots despite the assumed presence of ethylene from the apples (McKeown and Loughheed 1981). A sensory panel compared those carrots with those stored in 2% O₂ and bags of slaked lime to absorb CO₂ and found that those from the hypobaric storage were superior.

Diseases

The most prominent storage diseases were bacteria soft rot (*Pectobacterium carotovora* and *Pseudomonas marginalis*), grey mould (*Botrytis cinerea*), Rhizopus soft rot (*Rhizopus spp.*), watery soft rot (*Sclerotinia sclerotiorum*) and sour rot (*Geotrichum candidum*) (Snowdon 1991). Fatima *et al.* (2009) found

Geotrichum candidum and *Cladosporium cladosporioides* infecting carrots in on the market in Karachi, Pakistan, with *G. candidum* the most common. Other diseases include

- Bacterial soft rot *Erwinia chrysanthemi* E. *carotovora* subsp. *carotovora* (Jones 1901) = *Pectobacterium carotovorum* subsp. *carotovorum* (Jones 1901) Hauben *et al.* 1999, *comb. nov.* E. *carotovora* subsp. *atroseptica* (van Hall 1902) Dye 1969 = *Pectobacterium carotovorum* subsp. *atrosepticum* (van Hall 1902) Hauben *et al.* 1999, *comb. nov.* *Erwinia* spp. and *Pseudomonas* spp.
- Thielaviopsis rot *Thielaviopsis basicola* (Berk & Broome) Ferraris.
- Black rot *Alternaria* spp.
- Crator rot *Athelia arachnoidea* (Berk.) Julich.
- Grey mould rot *Botrytis cinerea* Pers.:Fr. [anamorph].
- Licorice rot *Mycocentrospora acerina* (R. Hartig) Deighton = *Centrospora acerina* (R. Hartig) A. G. Newhall.
- Rhizopus woolly soft rot *Rhizopus arrhizus* A. Fischer = *R. oryzae* Went & Prinsen Geerligs *R. stolonifer* (Ehrenb.: Fr.) Vuill. = *R. nigricans* Ehrenb.
- Collar rot or Sclerotium rot *Sclerotium rolfsii* Sacc. (teleomorph: *Athelia rolfsii* (Curzi) Tu & Kimbrough = *Corticium rolfsii* Curzi).
- Sour rot *Geotrichum candidum* Link (teleomorph: *Galactomyces geotrichum* (E.E. Butler & L.J. Petersen) Redhead & Malloch) *G. penicillatum* (do Carmo Sousa) Arx.
- Violet root rot *Helicobasidium purpureum* Pat.
- Cottony rot or watery soft rot *Sclerotinia minor* Jagger *Sclerotinia sclerotiorum* (Lib.) de Bary.
- Blue mold rot (blue green mold) *Penicillium expansum* Link.
- Aspergillus black mould *Aspergillus niger* Tiegh.
- Watery soft rot *Sclerotinia minor* Jagger, *S. sclerotiorum* (Lib.) de Bary. *S. rolfsii* Sacc. *Botrytis cinerea* Pers.:Fr.

Fresh carrots were exposed to a continuous atmosphere of 40–60 nl L⁻¹ ozone during storage for up to 6 months at 0.5 °C and greater than 95% r.h. to determine its effect on decay caused by *Sclerotinia sclerotiorum* and *Botrytis cinerea* and quality attributes. These were compared to carrots in a flow through system with no ozone. Lesions on carrots

inoculated with *S. sclerotiorum* at the beginning of the storage period were reduced in length but the subsequent rate of lesion expansion over time was similar for both treatments. Lesion size and rate of expansion on carrots inoculated with *B. cinerea* were reduced by ozone. Aerial mycelium of both pathogens was markedly reduced in the ozone treatment, but sporulation of *B. cinerea* was stimulated, characterized by dense mats of short conidiophores on the lesions. Susceptibility to *S. sclerotiorum* increased with storage time while susceptibility to *B. cinerea* peaked at 4 months and then decreased possibly related to carrot moisture loss. The incidence of carrots harbouring visible saprophytic mould on the crown was substantially reduced in the ozone treatment. Ozone-induced injury, appearing as blotches of brownish discoloured periderm, was slight, but increased with time, whereas carrots in the control treatment did not become discoloured. Ozone treatment had no effect on fresh weight loss, sprouting of carrot crowns, or on concentrations of glucose, fructose, sucrose or galactose. Levels of isocoumarin were slightly elevated and averaged 17.8 mg kg⁻¹ compared with 12.1 mg kg⁻¹ in the controls and may have been associated with reduced lesion growth by *B. cinerea*. The ozone treatment may be useful for reducing nesting caused by *S. sclerotiorum* and *B. cinerea* in carrots destined for the processing market where any ozone-induced discolouration would be removed during peeling (Hildebrand *et al.* 2008).

Cassava

Euphobiaceae

Manihot esculenta Crantz. Other common names include manioc, tapioca, Brazilian arrowroot, mandioca, yautia and yuca. *M. esculenta* is not known in the wild state and may have arisen by mutation or hybridization. Some 98 species of *Manihot* have been found, all are native of tropical regions of the Americas and are particularly concentrated in Brazil and Mexico (Nassar *et al.* 2008). Species found in other tropical regions were reported to be introductions. The probable centre of origin was in the area of southern Mexico northern Guatemala or north eastern Brazil, or both. It was cultivated in Peru 4000 years ago and in Mexico 2000 years ago and subsequently spread throughout central and tropical

South America. It was taken by the Portuguese to Africa in the 16th century, but its spread in Africa was slow until the end of the 19th century and first half of the 20th century. The crop has become important throughout the tropics, under a wide range of conditions of climate and soil, with West Africa, Brazil, Indonesia, Colombia and Thailand being major producers. Its resilience in marginal environments is particularly important for the rural poor (Ortiz 2007). Total world production of cassava in 2010 was estimated by FAO (2012) as 230,265,639 tonnes. Cassava leaves are also used as a spinach-type food and total world production of cassava leaves in 2010 was estimated by FAO (2012) as 85,007 tonnes.

It is a perennial shrub, with latex in all its parts. There are over 100 cultivars and there is great variation in the form of the plant with the height ranging from about 1 to 3 m or more. The stems are usually slender and glabrous, with leaves borne near the apex. The lower parts of the stems have nodes with prominent leaf scars (Figure 20). It is cultivated for its enlarged starch-filled roots that contain nearly the maximum theoretical concentration of starch on a dry weight basis among food crops (Kay 1987, O'Hair 1995). As the shrub grows they develop secondary



Figure 20 Cassava showing harvest maturity.

thickening of adventitious roots close to the stem. There are normally up to 10 tuberous roots per plant, which are cylindrical or tapering, up to 15 cm in diameter and up to 1 m long (Ingram and Humphries 1972) (Figure 21). They have a brown outer skin and a white, purple or pink inner skin, with white flesh. In Sub-Saharan Africa and Latin America, the crop is mainly grown for human consumption, while in Asia and parts of Latin America it is also used for animal feed and starch extraction (Nassar *et al.* 2008).

The roots can contain the cyanogenic glucoside linamarin, which is converted into hydrogen cyanide by the enzyme linamarase. Another cyanogenic glucoside, lotaustralin, has also been found but at levels of about one-twentieth of linamarin. The level of cyanide varies considerably between cultivars. Twenty-eight cassava cultivars were measured for hydrogen cyanide in Fiji and ranged from 14 to 121 mg kg⁻¹ of fresh peeled tuber (Aalbersberg and Limalevu 1991). In other work linamarin equivalent was measured as 2–1000 mg HCN kg⁻¹ of root tissue (Pihlanto 2011). Kay (1987) reported that HCN content could vary from 10 to 490 mg kg⁻¹ being highest in roots grown on soils of low fertility, particularly if there is a potassium deficiency and also in the dry season. For consumption as a vegetable, after boiling or roasting, clones that have a low hydrocyanic acid content are used e.g. the cultivar Chiroso Armenia in Colombia. These varieties or cultivars are often referred to as *sweet cassava*. Removal of



Figure 21 Cassava on sale in a Californian supermarket with waxed cassava from Costa Rica (left) and Chinese yuca (right). See colour plate section.

the cyanogenic glucosides that occur especially in the clones described as bitter cassava is important since it is highly toxic. Grating followed by fermentation and sometimes heating on a flat plate normally removes it. Gari, a staple fermented meal in West Africa, is prepared in this way. Washing in constant running water or repeated boiling in changes of water is also used (Thompson 1972b, Cooke *et al.* 1985).

The typical range of composition for the edible portion of the roots was energy 607 kJ 100 g⁻¹ water 62–65%, total carbohydrate 32–35%, protein 0.7–2.6%, fat 0.2–0.5%, fibre 0.8–1.3%, ash 0.3–1.3%, calcium 33 mg 100 g⁻¹, iron 0.7 mg 100 g⁻¹, thiamine 0.06 mg 100 g⁻¹, riboflavin 0.03 mg 100 g⁻¹, niacin 0.6 mg 100 g⁻¹, ascorbic acid 20–30 mg 100 g⁻¹ and vitamin B 10 IU 100 g⁻¹ (Kay 1987). Chávez *et al.* (2005) found that the total carotenoid content in roots ranged from 1.02 to 10.40 10 µg g⁻¹ fresh tissue. The chemical content was given by USDA Nutrient Database (2012a) in Table 39.

Physiological deterioration

There are two types of deterioration that occur during storage, one physiological and the other due to microorganisms. Roots can deteriorate within a day or so of harvesting because of a physiological disorder called vascular streaking (Thompson and Arango 1977). The vascular bundles turn a bluish black colour and can be seen as dark points across the root when it is cut at right angles (Figure 22). Kay (1987) reported that physiological deterioration was essentially a humidity-sensitive wound response with increases in enzyme activity leading to the production of phenols including catechins and leucoanthocyanidins that polymerize to form condensed tannins. Reilly *et al.* (2001) showed that physiological deterioration was related to oxidative processes. In a comparison between highly susceptible and less susceptible cultivars they suggest that high levels of catalase activity may play a role in delaying the deterioration response. Visible signs of discolouration are at first blue, becoming brown and initially usually appear in the peripheral vascular bundles and spread to adjacent parenchyma. Occlusions and tyloses have also been observed in the xylem parenchyma and there is an increase in respiration rate and starch hydrolysis. Later microbial activity has been shown to cause further deterioration (Rickard *et al.* 1979). A



Figure 22 Cassava roots cut to display vascular streaking on the three left-hand side ones. (Photo: Dr R.H. Booth.)

low susceptibility to vascular streaking was correlated with a low dry matter and a high sugar content (van Oirschot *et al.* 2000).

Methods of control vascular streaking include curing and cutting off the stem 20–30 cm above the ground 2–3 weeks before harvesting. In experiments by van Oirschot *et al.* (2000) six cassava cultivars were harvested 0–39 days after having been pruned in this way. They found that after pruning their susceptibility to vascular streaking for all the cultivars tested was drastically reduced, reaching a minimum of around 25% of the original value for an interval between pruning and harvesting of up to 25 days. With a longer interval the plants slowly developed a new leaf canopy, normal carbon assimilation recommenced and starch content increased. They developed similar levels of vascular streaking to those that had not been pruned. Kay (1987) reported that some measure of control has been obtained by storing the roots at low temperature or in air with low O₂ levels or in increased CO₂. Akhimienho (1999) found that storage for 9 days at 5 °C inhibited vascular streaking but its incidence increased with increasing temperature over the range 10–25 °C. The sugar content and the sugar : starch ratio was positively correlated with their resistance to vascular streaking (van Oirschot *et al.* 2000). Chávez *et al.* (2005) in a study of several hundred clones reported that higher carotenoid levels in roots might reduce or delay the onset of vascular streaking.

Akhimienho (1999) found that in 0% O₂ with 40–65% CO₂ and the balance N₂ both vascular

streaking and mould growth was inhibited over the 10 day experimental period at different temperatures in the range 5–35 °C. She also found that 21% O₂ with 10–20% CO₂ inhibited vascular streaking and mould growth, but storage in 1 or 5% O₂ had no apparent effect. Conversely Zapata (2001) found that storage in less than 5% O₂ delayed the onset of postharvest physiological deterioration. The cultivar Valencia was harvested from 12-month-old plants. The roots were then coated with paraffin wax and stored at 25 °C for 3 days in either 54–56% r.h. or 95–98% r.h. and at O₂ levels of either 21% (air) or 1% by Aracena *et al.* (1993). Storage in 54–56% r.h. in air increased vascular streaking development with an incidence of 46%, but storage in 54–56% r.h. in 1% O₂ reduced vascular streaking to an incidence of 15%. However, at 95–98% r.h., irrespective of the O₂ level, vascular streaking incidence was reduced to only 1.4%. They concluded that the occurrence of vascular streaking was primarily related to water stress in the tissue, while O₂ was secondarily involved.

There is evidence of genetic resistance to postharvest physiological deterioration. CIAT (2006) reported an inter-specific hybrid between cassava and propagated specimens of a Mexican collection of *M. walkerae* which was the only known source of resistance to postharvest physiological deterioration. Owiti *et al.* (2011) investigated the molecular changes during postharvest deterioration and found that it was a highly regulated complex process involving proteins that are potential candidates for biotechnology approaches to reduce postharvest physiological deterioration. This included regulated proteins that had not previously been associated with physiological deterioration after harvesting including linamarase, glutamic acid-rich protein, hydroxycinnamoyl transferase, glycine-rich RNA binding protein, β -1,3-glucanase, potassium, dehydroascorbate reductase, allene oxide pectin methylesterase, maturase cyclase and proteins involved in signal pathways.

Harvesting and handling

The exact time when the roots are ready for harvesting depends on the cultivar and growing conditions. Extensive studies have indicated that delays in harvesting did not seriously affect tuber quality or yield. Generally cassava reaches maturity in 9–24 months

after planting. A few quick growing cultivars can be harvested in 6–7 months but good yields are normally only obtained after 9–12 months. Generally when used as a vegetable the tubers are harvested within 12 months of planting, otherwise they may become very fibrous. However, in Trinidad Wickham and Wilson (1988) harvested roots of the cultivars White Stick, Black Stick and M Col.22 at intervals starting 11 month after planting and found that roots left in the ground for 20 weeks after the normal harvest time retained acceptable cooking quality for human consumption.

Because of its shape, the swollen roots are difficult to harvest without damaging (Figure 20). The roots are commonly just pulled from the ground by the stem but this can result in damage, especially when the soil is dry and hard, resulting in rapid postharvest deterioration. In some cases the soil is carefully dug away from each tuberous root individually to avoid damaging them. Kay (1987) reported that tops are chopped off using a machete or by machine. She also reported that machine harvesting was being increasingly employed. A number of devices have been used, from simple ridge breakers, which expose the roots and leave them to be picked up by hand, to relatively sophisticated equipment resembling potato harvesters. Damage to tubers is still a problem with mechanical harvesting, but smaller tubers are more easily lifted and are less liable to damage. Mechanical harvesters for processing are common but the roots must be processed quickly after harvest to avoid deterioration. In the 1970s CIAT at Palmira in Colombia developed a cassava harvester for the fresh market. It consisted of equipment towed behind a tractor that gripped the stem and at the same time undercut the roots so that they were pulled from the soil. In tests it worked well on flat land when the soil was moist, but it was ineffective on sloping dry soils. Odigboh (1991) described a cassava harvester that could remove the crop from the ground with minimum damage to the roots when plants were grown in ridges. It operated at a theoretical rate of 0.25–0.4 ha h⁻¹ depending on the soil type and field conditions. It had two gangs of reciprocating power take-off drivers that dug two opposite sides of the ridge from the furrow bottom to remove the cassava roots.

In Colombia cassava is packed directly into sacks containing 75 kg in the field. Because these sacks are so heavy to carry they are borne on workers' backs.

When loading lorries they are dropped with some considerable force from the workers' backs to the bed of the lorry. A simple solution would be to reduce the pack size to say 25 kg. This, however, proved unacceptable to the trade and other methods of reducing wastage had to be investigated (Thompson 1978), but it has proved difficult to change the system that workers are used to.

Curing

Some work in Colombia (Booth 1975) indicated that cassava could be successfully cured by exposure to 25–40 °C and 80–85% r.h. Rickard (1981) reported that the best conditions for curing (wound healing) of cassava were 34–36 °C with 95–100% r.h. Suberization occurred in 1–4 days with periderm formation 3–5 days later. In a subsequent study Akhimienho (1999) showed that curing of tissue damaged by cutting was related to the depth of cut (Table 40). Shallow wounds of 2 mm deep could be cured, but wounds of 8–10 mm deep showed no curing over the 10-day period of the study.

Waxing

Coating with a fungicidal wax was stated to extend the storage life of cassava roots for up to 2 months under ambient conditions in the tropics (Subramanyam and Mathur 1956). Young *et al.* (1971) and Thompson and Arango (1977) confirmed that dipping the roots in paraffin wax kept them in good condition for 1–2 months at room temperature in Bogotá in Colombia. This coating treatment is currently applied to roots exported from Costa Rica where the following procedure was successfully developed:

1. Harvest the roots with care to avoid damage.
2. Wash thoroughly directly after harvest to remove all the surface soil.
3. Dry in an oven at 50 °C for 2 h.



Figure 23 Waxed cassava on arrival in Britain after sea-freight transport from Costa Rica in July 2009. See colour plate section.

4. Immerse the roots, while still hot, in paraffin wax at 62 °C. At 64 °C and over fumes are produced by the wax that can detrimentally affect the workers. If the roots are immersed in paraffin wax without the 2 h drying the wax does not bind closely with the surface of the root and it may crack and the wax will be dislodged during subsequent handling.
5. Place on racks to allow them to cool.
6. Pack them in cartons and transport them at 12 °C (Figure 23).

Storage structures

In situ storage effectively means delaying the harvest of the crop until it is required, but it does mean that the land where the crop is being grown remains occupied and a new crop cannot be planted there. The crop may also be exposed to pest and disease attack. It was shown that delayed harvesting could result in reduced acceptability and reduced starch content and the risk of preharvest losses (Rickard and Coursey

Table 40 Effects of time and temperature at 95% r.h. on the number of layers of cells that developed during curing of 2 mm deep cuts at 25 or 35 °C in cassava roots (source: adapted from Akhimienho 1999)

Days after cutting Temperature (°C)	1		2		4		8		10	
	25	35	25	35	25	35	25	35	25	35
Lignified	0	0	1.5	1	2.5	2.5	4.5	4	4.5	4
Suberized	0	0	0	0	0.5	0.5	1	1	3	3

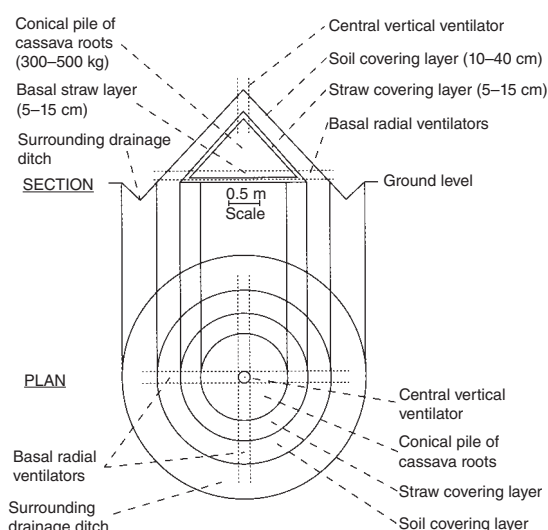


Figure 24 Diagram of a clamp designed for cassava storage. (Source: Booth 1975.)

1981). In Uganda fresh cassava was reported to be stored mainly by reburying or placing in water for a few days (Ameny 1990). Clamps were developed for cassava storage in Colombia (Figure 24) where storage for over 8 weeks was reported but after 1 month only 75% of the original weight was in a marketable condition with subsequent losses being usually only small (Booth 1976, 1977). The clamps were built in the field with the cassava roots piled on layers of straw. These were covered with layers of straw and soil with ventilation points. Extra straw covering may be needed in hot climates (CIP 1981).

Wickham and Wilson (1988) dipped roots in benomyl fungicide and stored them in polyethylene film lined boxes filled with sand and/or sawdust. Vascular streaking occurred if roots were removed from moist storage and placed under ambient conditions, unless moist storage was continued for 11–14 weeks depending on cultivar or variety. Callus, adventitious roots and secondary adventitious roots grew at the distal end of all stored cultivars. Some of the cassava developed a spongy appearance and large cavities under moist storage and especially on removal to ambient conditions. Cooking quality was maintained in all stored roots for the first 6 weeks but there was considerable decline in quality after 8–11 weeks depending on cultivar or variety. Benomyl use is not permitted in many countries.

Storage conditions

Surprisingly Mercantilia (1989) reported that their shelf life in simulated room temperature of 20 °C and 60% r.h. was 2–4 weeks. Refrigerated storage recommendations include

- 1.7–3.3 °C and 80–90% r.h. for 2 weeks with 11% loss but they also had internal browning and mould growth (Singh and Mathur 1953);
- 13–14 °C for 9 days in Puerto Rica (Burton 1970);
- 3 °C gave losses of 6–7% per week (Ingram and Humphries 1972);
- 0 °C and 85% r.h. for 23 weeks (Pantastico 1975);
- 0–2 °C and 85–90% r.h. for several months (Tindall 1983);
- 0–2 °C and 85–90% r.h. for about 4 weeks (Kay 1987);
- 1 °C for 90% r.h. for 5–6 months (Mercantilia 1989);
- 0–2 °C and 85–90% r.h. for 5–6 months (Snowdon 1991);
- 10 °C and 90–95 r.h. for 10–14 days (SeaLand 1991);
- 10 °C and 80% r.h. delayed the onset of postharvest physiological deterioration by 2 weeks (Zapata 2001).

Modified atmosphere packaging

Oudit (1976) showed that freshly harvested roots could be kept in good condition for up to 4 weeks when stored in PE bags. Avere (1967) found that wrapping the roots in moist paper and then sealing them in PE film bags prevented vascular streaking during 8 days of storage at either 10 or 40 °C with only slight development at 25 °C. Dipping the roots in a fungicide (benomyl or thiabendazole) and packing them in plastic film directly after harvest reduced vascular streaking during storage for 8 days at 22–24 °C compared to roots stored unwrapped (Thompson and Arango 1977). However the use of the fungicides benomyl and thiabendazole is now restricted in many countries.

Diseases

Postharvest diseases of cassava include *Fusarium* rot *Fusarium solani* (H. Mart.) Sacc. (teleomorph: *Nectria haematococca* Berk. & Broome), Botryodiplodia rot *Botryodiplodia theobromae* Pat., *Trichoderma* rot *Trichoderma harzianum* Rifai, *Trichoderma viride*

Pers. Ex S.F. Grey, Bacterial soft rot *Erwinia carotovora* subspecies *carotovora* (L. R. Jones), Rhizopus rot *Rhizopus oryzae* Went & Prinsen Geerligs and Aspergillus rot *Aspergillus flavus* Link:Fr. Ubalua and Oti (2007) found that cassava roots had 4% rots due to *Rhizopus oryzae* and 44% due to *Aspergillus flavus*. During subsequent storage for 3 weeks the roots that had been treated with *Trichoderma viride* showed a reduction in the frequency of occurrence of the normal root surface mycoflora and the two pathogens. *B. theobromae* and *R. oryzae* were isolated only in the first week of storage and at a frequency of 3 and 2% rot, respectively, after treatment. *A. flavus* and *F. solani* persisted throughout the whole storage period with 2 and 3% rot, respectively, on the third week. They suggested that *T. viride* was highly antagonistic and competed with other mycoflora on the root surface.

Cauliflower

Brassicaceae, Cruciferae

Brassica oleracea var. *botrytis* L. or *B. oleracea* L. Botrytis Group. In the wild *B. oleracea* is native to the Mediterranean region of Europe. Cauliflowers appear to have been developed in Italy possibly from germ plasm brought from the eastern Mediterranean in Roman times with the white headed cultivars having been developed only over the past 400 years (Dixon 2007). The edible portion is the curd, which is made up of the abortive flowers on hypertrophied branches. Total world production for cauliflowers and broccoli in 2010 was estimated by FAO (2012) as 19,794,339 tonnes.

Preharvest factors

Kodithuwakku and Kirthisinghe (2009) applied different levels of urea fertilizer to growing cauliflowers and found no significant difference in the postharvest quality of curds. However, they found that applying 50% of the recommended nitrogen fertilizer resulted in an extension in their postharvest life of 6 days longer than other treatments in storage in ambient conditions.

Harvesting and handling

Harvesting should be when the curds have reached an acceptable size, but before the flower stalks elongate



Figure 25 Tractor-mounted conveyer belt to facilitate hand harvesting with a trailer used for field packing.

and become discoloured, ricy or leafy. If harvesting is delayed they can have a tough texture and an unpleasant flavour when they are over developed. However, this is not likely to occur until heads are considerably over mature and unmarketable (John Love, personal communication). The plants are cut just below the lowest leaf and they should be transported to the store or packhouse without pruning the outer leaves as they protect the curd from damage. In practice the outer leaves are often cut to just above the curd and they are loaded into crates for transport to the packhouse or packed directly into boxes for marketing. Mechanical aids to harvesting involve cutting them by hand and placing them on a conveyer on a mobile packing station, which is slowly conveyed across the field (Figures 19 and 25) (Holt and Sharp 1989).

Cauliflower should be cooled by high humidity forced-air cooling as soon as possible after harvest. Vacuum cooling, air cooling in a conventional cold store and hydrocooling were all less suitable (MAFF n.d.).

Postharvest physiology

Respiration rate was strongly affected not only by temperature but also by the O_2 level in the storage atmosphere (Table 41); however, the effect of reduced O_2 was greater at 20 °C compared to lower temperatures. Inaba *et al.* (1989) found that there was an increased respiration rate in response to ethylene at 100 μL^{-1} for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Respiration rate

Table 41 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of April Glory cauliflowers (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	20	34	45	67	126
In 3% O ₂	14		45		60

was decreased in 3% O₂ compared to storage in air (Romo Parada *et al.* 1989).

Storage

Storage is commonly in half tonne slatted boxes, which are covered with polyethylene film after cooling to maintain humidity. If they lose excess moisture, more than about 5%, they can have a wilted appearance and the curds may be rubbery. Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2 days (Mercantilia 1989). They will freeze at about -1.2 to -1.1 °C (Wright 1942) or -1.17 to -0.94 °C (Weichmann 1987). Refrigerated storage recommendations include

- -1 °C and 90% r.h. for 3 months (Wardlaw 1937);
- 0–1 °C and 85–90% r.h. for 3–6 weeks (Anonymous 1967);
- 0 °C and 90–95% r.h. for 2–4 weeks (Phillips and Armstrong 1967, Anonymous 1968, Hardenburg *et al.* 1990);
- 1 °C and 90–95% r.h. for up to 3 weeks (Shipway 1968);
- 0–1.7 °C and 85–90% r.h. for 7 weeks with 30.4% loss for Snowball (Pantastico 1975);
- 0–1 °C and 95% r.h. for up to 28 days with about 30% weight loss (Tindall 1983);
- 4 °C for approximately 7 days (Tindall 1983);
- 0 °C and 90–95% r.h. for 42 days (Mercantilia 1989);
- 2 °C for 32 days (Mercantilia 1989);
- 4 °C for 18 days (Mercantilia 1989);
- 8 °C for 8 days (Mercantilia 1989);
- 0–1 °C and 85–90% r.h. for 2–3 weeks (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 20–30 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1991).

Controlled atmosphere storage

Considerable work has been done in Holland (originally in the Sprenger Institute) since the 1950s. This work has shown very little benefit of CA storage, but storage at 0–1 °C and greater than 95% r.h. with 5% CO₂ and 3% O₂ gave a better external appearance than cold storage alone but had no effect on curd quality (Mertens 1989). Other recommendations include

- 0 °C with 10% CO₂ and 10% O₂ for 5 weeks (Wardlaw 1937);
- 10% CO₂ and 11% O₂ for 5 weeks (Smith 1952);
- 0 °C in 0–3% CO₂ + 2–3% O₂ (Stoll 1972);
- 4.4 or 10 °C with 5% CO₂ but some injury was evident after the curds were cooked (Ryall and Lipton 1979);
- 0 °C in 5–10% CO₂ + 5% O₂ for 50–70 days (Monzini and Gorini 1974);
- 5–6% CO₂ + 3% O₂ (Tataru and Dobreanu 1978);
- a maximum of 5% CO₂ and a minimum of 2% O₂ (Fellows 1988);
- 0 °C and 100% r.h. 3% O₂ and 2, 5 or 5% CO₂ were still acceptable and marketable after 7 weeks of storage (Romo Parada *et al.* 1989);
- 0 °C and 100% r.h. 3% O₂ and 10% CO₂ had yellowing and leakage of the curd after 7 weeks of storage (Romo Parada *et al.* 1989);
- 1 °C with 2.5% CO₂ and 1% O₂ for 71–75 days for autumn cauliflowers or in the same atmospheres but at 5 °C for 45 days (Adamicki 1989);
- 5% CO₂ or more and 2% O₂ or less injured the curds and did not extend their storage life (Hardenburg *et al.* 1990);
- 0 °C with 2–5% CO₂ and 2–5% O₂ (SeaLand 1991);
- 0–5 °C with 2–5% CO₂ and 2–5% O₂ that had a fair effect but was of no commercial use (Kader 1985, Kader 1992);
- 0 °C in 3% O₂ + 5% CO₂ reduced weight loss and discolouration but did not affect free sugar or glucosinolate profiles compared to those stored in air at the same temperature for up to 56 days (Hodges *et al.* 2006).

Curds of cultivar Primura were stored successfully for 6–7 days at 0–1 °C and 90–95% r.h. in circulating air and for 20–25 days in 4–5% CO₂ + 16–27% O₂ (Saray 1988). In Poland both summer and autumn crops that were stored at 1 or 5 °C in 2.5% CO₂ + 3%

O₂ or 5% CO₂ + 3% O₂ had better leaf colour, curd colour, firmness and market value than those stored in air. Curds of the autumn crop stored in 2% CO₂ + 3% O₂ had a superior composition to those stored in other controlled atmosphere conditions at both storage temperatures (Adamicki and Elkner 1985). In Turkey Kaynaş *et al.* (1994) stored the cultivar Iglo in 3% CO₂ + 3% O₂ for a maximum of 6 weeks, which was double their storage life in air, with a shelf life of 3 days at 20 °C.

In other work controlled atmosphere storage did not extend their storage life and CO₂ levels of 5% or more or of 2% O₂ or less injured the curds (Hardenburg *et al.* 1990). After storage at either 4.4 or 10 °C with levels of 5% CO₂ in the storage atmosphere some injury was evident after the curds were cooked (Ryall and Lipton 1979). Mertens (1989) concluded that in storage at 0–1 °C and less than 95% r.h. for 4 or 6 weeks with subsequent shelf life studies at 10 °C and 85% r.h. that storage in 5% CO₂ + 3% O₂ had a very small effect, if any, on the respiration rate of the curds. Work on the cultivar Pale Leaf 75 by Tomkins and Sutherland (1989) with curds stored at 1 °C for up to 47 days in air or in 5% CO₂ + 2% O₂ or 0% CO₂ + 2% O₂ showed that curds stored in 2% O₂ alone suffered severe, irreversible injury and were discarded after 27 days of storage. After 47 days of storage in 5% CO₂ + 2% O₂ plus the 4-day marketing period, curd quality was acceptable owing to the reduction in incidence of soft rot and black spotting noted in air-stored curds. In air, curds were unsalable after only 27 days of storage plus the 4-day marketing period. Storage at 4 °C in 18% O₂ + 3% CO₂ for 21 days had no significant effect on the growth of micro-organisms compared to those stored in air at the same temperature (Berrang *et al.* 1990). Storage for 8 days at 13 °C in air or 15% CO₂ + 21% O₂, + 64% N₂ accelerated the deterioration of microsomal membranes during storage and caused an early loss in lipid phosphate (Voisine *et al.* 1993). Menniti and Casalini (2000) stored cauliflowers at 0 °C and found that concentrations of 10, 15 or 20% CO₂ in the atmosphere delayed leaf yellowing and rot caused by *Alternaria brassicicola*, but caused injury inside the stem, and developed off-flavours and odours after cooking. Romo Parada *et al.* (1989) reported that 0 °C and 100% r.h. with 3% O₂ + 10% CO₂ caused softening, yellowing and increased leakage.

Modified atmosphere packaging

Plastic films or cellophane wraps can be used to protect the curds during storage and transport. The cultivar Siria was grown in Spain in winter with three harvesting periods of January, March and April by Artes and Martinez (1999). They carried out simulated marketing trials of 1 week at 1.5 °C followed by 2.5 days at 20 °C packed in different films: 14.5 µm PVC, 11, 15 or 20.5 µm LDPE or 11.5 µm microwavable LDPE. After the shelf life simulation, the best results were obtained in the 11.5 µm LDPE film. Gas composition was about 16% O₂ and 2% CO₂ during cold storage and about 11% O₂ and 3.5% CO₂ during retail sale simulation. The overall quality, yellowing and browning of the head and *Alternaria* spp. development were at similar levels among the films studied. Weight loss was considerably lower for LDPE films than for the PVC film. Menjura Camacho and Villamizar (2004) studied ways of reducing wastage of cauliflowers in the central markets of Bogotá and found that the best treatment was packing them in LDPE with 0.17% perforations. Menniti and Casalini (2000) found that PVC film wrapped around each cauliflower reduced weight loss and retarded yellowing during storage for 5 days at 20 °C. Curd colour, odour and compactness of the curd remained acceptable for up to 14 days at 6 °C in non-perforated polyethylene bags (Rahman *et al.* 2008). The highest ascorbic acid content, 41 and 23 mg 100 g⁻¹, β-carotene content, 26 IU 100 g⁻¹ and 14 IU 100 g⁻¹ were in non-perforated PE bags after 7 days and 14 days of storage at 6 °C. Kaynaş *et al.* (1994) stored the cultivar Iglo in 30 µm thick polyethylene film bags, polyethylene film bags with one 5 mm diameter hole per kilogram head, 15 µm-PVC film bags or not wrapped for various times at 1 °C and 90–95% r.h. They found that they could be stored for a maximum of 6 weeks in PVC film bags with a shelf life of 3 days at 20 °C, which was double the storage life of those stored non-wrapped. The permeability of the PVC film used in the studies was given as 200 g of water vapour m⁻² day⁻¹ and 12,000 ml O₂ m² day⁻¹ atm.⁻¹.

Hypobaric storage

Ward (1975) found that after storage at 3 °C for 5 weeks the cauliflowers in 75 mm Hg were still in good condition while those stored in atmospheric

pressure had yellowing curds and senescent leaves. Cauliflowers were kept for 4 days at 1.1 °C then 0 °C and 10, 20 or 40 mm Hg or atmospheric pressure for 21 days was assessed for quality after a shelf life at 10 °C by Burg (2004). At the end of the shelf life test the ones that had been stored in atmospheric pressure had leaves that were yellow and dry and abscised with minimal handling. Those that been in hypobaric storage had some yellowing but remained attached when handled and had a superior appearance especially those that had been stored at 10 or 20 mm Hg.

Celeriac

Apiacea

Apium graveolens L. var. *rapaceum* (Mill.). Other common names include turnip rooted celery, edible root celery and apio nabo. Celery is the same species and is referred to as *A. graveolens* var. *dulce* (Mill.) and *A. graveolens* var. *secalinum* (Alef). The edible portion is the swollen base of the stem (Figure 26), which superficially resembles a turnip but is not actually part of the root as is the turnip. Celeriac is about 10 cm in diameter, irregular in shape and subglobose, with a brownish skin and white flesh tasting of celery. Leaf stalks are not swollen, as they are in celery, and can have a bitter taste and therefore are not eaten. Dambrauskienė *et al.* (2009) investigated nine cultivars and found that there was considerable variation in yield. The best cultivars were Anita, Brilliant, Diamant and Makar with an average yield of 30 tonnes ha⁻¹ while the cultivar Frigga had only 18 tonnes ha⁻¹.



Figure 26 Celeriac on sale at a UK green grocer's shop in 2013. See colour plate section.

Table 42 The composition of celeriac for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	88.00 g	Thiamine	0.050 mg
Energy	42 kcal	Riboflavin	0.060 mg
Protein	1.50 g	Niacin	0.700 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.165 mg
Carbohydrate, by difference	9.20 g	Folate	8 µg_DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Sugars, total	1.60 g	Vitamin A	0 µg_RAE
Calcium	43 mg	Vitamin A	0 IU
Iron	0.70 mg	Vitamin E (α-tocopherol)	0.36 mg
Magnesium	20 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	115 mg	Vitamin D	0 IU
Potassium	300 mg	Vitamin K (phylloquinone)	41.0 µg
Sodium	100 mg	Fatty acids, total saturated	0.079 g
Zinc	0.33 mg	Fatty acids, total monounsaturated	0.058 g
Total ascorbic acid	8.0 mg	Fatty acids, total polyunsaturated	0.148 g

Total sugar for most cultivars varied between 1.9 and 2.4% while Anita, Alba and Makar had 2.6–2.9%. Ascorbic acid varied with the highest being Alba with 14.2 mg 100 g⁻¹ and Mentor with 13.8 mg 100 g⁻¹ (Dambrauskienė *et al.* 2009). Kresic *et al.* (2004) gave the following analysis for celeriac: 11.4% total dry matter, about 0.94% minerals, of which potassium was 414 mg 100 g⁻¹, about 1.55% of protein, 0.33% fat, 2.25% of total sugars, 4.23% total dietary fibre, 1000 mg kg⁻¹ vitamin K and 60–83 mg kg⁻¹ vitamin C. The chemical content was given by USDA Nutrient Database (2012a) in Table 42.

Harvesting

Harvesting is when it has reached an acceptable size. In northern Europe this is in the autumn. The tops are usually twisted off or cut-off at harvest.

Postharvest physiology

Morris (2001) reported that rates of ethylene production were low at less than 0.1 µl kg⁻¹ h⁻¹ at 20 °C, but that they may be slightly sensitive to ethylene. He also gave their respiration rate in Table 43.

Table 43 Respiration rate of celeriac at different temperatures (source: adapted from Morris 2001)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	5–8
5	11–15
10	18–28
15	32–38
20	41–49

Storage

It can be stored for short periods of time in slatted crates in cool sheds (Lutz and Hardenburg 1968). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be 7 days (Mercantilia 1989). Refrigerated storage recommendations were as follows:

- 0–1 °C and 85–90% r.h. for 3–5 months (Anonymous 1967);
- 0 °C and 90–95% r.h. for 3–4 months (Lutz and Hardenburg 1968);
- 0 °C and 90–95% r.h. for 160 days (Mercantilia 1989);
- 2 °C for 120 days (Mercantilia 1989);
- 4 °C for 90 days (Mercantilia 1989);
- 8 °C for 50 days (Mercantilia 1989);
- 0 °C and 97–99% r.h. for 6–8 months (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 180–240 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 3–5 months (Snowdon 1991);
- 0 °C and 95–100% r.h. for 90–150 days (SPLFS 2001).

Controlled atmosphere storage

Hardenburg *et al.* (1990) found that storage in 5–7% CO₂ and low O₂ resulted in increased decay during 5 months of storage and therefore CA storage was not recommended. Pelleboer (1984) reported that storage in air at 0–1 °C gave better results than CA storage. CA storage recommendations were as follows:

- 0–5 °C with 2–3% CO₂ and 2–4% O₂ had only a slight effect (Saltveit 1989).
- 0 °C and 95–100% r.h. with 2–3% CO₂ and 2–3% O₂ had only a slight effect and had no advantages

over storage in air at the same temperature (SPLFS 2001).

- SeaLand (1991) also reported that controlled atmosphere storage had only a slight to no effect.

Celery

Umbelliferae

Apium graveolens var. *dulce* (Miller) Pers., *A. graveolens* var. *secalinum* (Alef). It is thought to have originated in the Mediterranean regions of northern Africa and southern Europe and possibly east towards the Himalayas. Whole Foods (n.d.) reported that celery has a long and prestigious history of use, first as a medicine and then later as a food. The initial mention of the medicinal properties of celery leaves dates back to the 9th century BCE when celery was referred to in Homer's *Odyssey*. The Ancient Greeks used the leaves as laurels to decorate their renowned athletes, while the ancient Romans used it as a seasoning, a tradition that has carried through the centuries. It was not until the Middle Ages that celery's use expanded beyond medicine and seasoning into use as a food but it did not become popular until the 18th century in Europe and was introduced in the United States early in the 19th century. It is a biennial herbaceous plant that grows to a height of 30–40 cm with the edible portion being the leaf petioles. They are often ridged up with soil as they grow to keep the bottoms of the petioles white; a process that is called blanching. Wild celery differs from its modern cultivars in that it had less petiole and more leaves. The petioles contain vitamin C and phthalides, which may help lower cholesterol and coumarins that may be useful in cancer prevention. The chemical content was given by Whole Foods (n.d.) in Table 44 and by USDA Nutrient Database (2012a) in Table 45.

Harvesting and handling

Harvesting is carried out when they reach a size acceptable to the market, but if this is delayed too long they become tough and fibrous. This is because the parenchyma cells break down leaving open spaces and producing a pithy texture and collenchyma fibres are produced giving a tough stringy texture (Wardlaw 1937).

Table 44 The composition of celery for 100 g⁻¹ fresh weight (source: adapted from Whole Foods n.d.)

Vitamin K	29.59 µg	Vitamin C	3.13 mg
Folate	36.36 µg	Manganese	0.10 mg
Vitamin A	453.49 IU	Calcium	40.40 mg
Potassium	262.60 mg	Vitamin B2	0.06 mg
Molybdenum	5.05 µg	Magnesium	11.11 mg
Fibre	1.40 g	Vitamin B5	0.25 mg

Table 45 The composition of celery for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	95.43 g	Thiamine	0.021 mg
Energy	16 kcal	Riboflavin	0.057 mg
Protein	0.69 g	Niacin	0.320 mg
Total lipid (fat)	0.17 g	Vitamin B-6	0.074 mg
Carbohydrate, by difference	2.97 g	Folate	36 µg_DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Sugars, total	1.83 g	Vitamin A	22 µg_RAE
Calcium	40 mg	Vitamin A	449 IU
Iron	0.20 mg	Vitamin E (α-tocopherol)	0.27 mg
Magnesium	11 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	24 mg	Vitamin D	0 IU
Potassium	260 mg	Vitamin K (phylloquinone)	29.3 µg
Sodium	80 mg	Fatty acids, total saturated	0.042 g
Zinc	0.13 mg	Fatty acids, total monounsaturated	0.032 g
Total ascorbic acid	3.1 mg	Fatty acids, total polyunsaturated	0.079 g

Vacuum cooling was the most suitable method, forced-air cooling with high humidity and hydro-cooling were also suitable and air cooling in a conventional cold store was less suitable (MAFF n.d.). After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of –1.7 to 0 °C the petiole temperature fell from 20 to 22 °C to 7 °C (Barger 1963). Lutz and Hardenburg (1968), Phillips and Armstrong (1967) and Wardlaw (1937) all recommended hydrocooling as soon as possible after harvest.

Postharvest physiology

Celery produces a small amount of ethylene, less than 0.1 µL kg⁻¹ h⁻¹ at 20 °C and it is not very sensitive to

Table 46 Respiration rates of celery at different temperatures (source: adapted from Hardenburg *et al.* 1986)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	10–20
5	13–26
10	20–42
15	26–54
20	46–95

Table 47 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of white celery (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	7	9	12	23	33
In 3% O ₂	5	–	9	–	22

low concentrations of ethylene when exposure occurs at low temperatures. At temperatures above 5 or 10 °C exposure to greater than 10 µL L⁻¹ ethylene can result in the rapid breakdown of chlorophyll in the tops, development of pithiness and increased decay (Mack 1927). Their respiration rates were given in Table 46. Respiration rate was strongly affected not only by temperature but also by the O₂ level in the storage atmosphere, fairly consistently at all the temperatures tested (Table 47).

Storage

Shelf life at 20 °C was given as only 1 day by Mercantilia (1989). They will freeze at about –1.3 to –1.1 °C (Wright 1942) or –0.67 to –0.22 °C (Weichmann 1987). Chilling injury was reported to occur during storage at –0.3 °C as a loosened epidermis that can be detected by twisting the stalk (Wardlaw 1937) and refrigerated storage recommendations were as follows:

- –0.3 to 0 °C and 95–98% r.h. (Wardlaw 1937);
- 0–1.1 °C, 2–4 °C, 0.6–1.7 °C and 0 °C all at 90% r.h. (Wardlaw 1937);
- 0 °C and 95% r.h. for up to 3 months if cooled rapidly after harvest (Phillips and Armstrong 1967);
- 0 °C and 95% r.h. for 8–10 weeks (Anonymous 1967);

- 0 °C and 90–95% r.h. for 2–3 months (Lutz and Hardenburg 1968);
- –0.5 to 1.5 °C and 90–95% r.h. for 12–14 weeks (Shipway 1968);
- 0 °C and 90–95% r.h. for 1–2 months (Amezquita Garcia 1973);
- –0.6 to 1 °C and 92–95% r.h. for 8 weeks with 15.2% loss (Pantastico 1975);
- 0 °C and 90–95% r.h. for up to 21 days (Tindall 1983);
- 4 °C for a maximum of 14 days with 15% weight loss (Tindall 1983);
- 0 °C and 90–95% r.h. for 28 days (Mercantilia 1989);
- 2 °C for 12 days (Mercantilia 1989);
- 8 °C for 4 days (Mercantilia 1989);
- 0 °C and 98–100% r.h. for 2–3 months (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 14–28 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 1–3 months (Snowdon 1991).

Controlled atmosphere storage

CA storage recommendations include

- 1–4% O₂ helped to preserve the petioles and 2.5% CO₂ 'may be injurious' but 9% CO₂ during 1 month's storage 'seemed harmless' (Pantastico 1975).
- 3–4% CO₂ + 2–3% O₂ which retained better texture and crispness than those stored in air (Garipey *et al.* 1985).
- 0–5 °C with 2–4% O₂ and 0% CO₂ or 0–5 °C with 0–5% CO₂ Kader (1985).
- 0–5 °C with 1–4% O₂ that had a fair effect but was of limited commercial use (Kader 1992).
- 0–5 °C in 1–4% O₂ + 3–5% CO₂ that had only a slight effect (Saltveit 1989).
- 0 °C in 5% CO₂ and 3% O₂ reduced decay and loss of green colour (Hardenburg *et al.* 1990).
- 0 °C with 2–5% CO₂ and 2–4% O₂ (SeaLand 1991).

Wardlaw (1937) found that 0, 4 or 10 °C for 7 days with 25% CO₂ resulted in browning at the base of the petioles, reduced flavour and a tendency for petioles to break away more easily. Reyes (1989) reviewed work on controlled atmosphere storage

and concluded that at 0–3 °C with 1–4% CO₂ and 1–17.7% O₂ storage could be prolonged for 7 weeks and he specifically referred to his work which showed that at 0–1 °C and 2.5–7.5% CO₂ with 1.5% O₂ market quality could be maintained for 11 weeks. Total weight loss of less than 10% over a 10-week period was reported by storing celery in 1% O₂ + 2 or 4% CO₂ at 0 °C. Significant increases in marketable celery resulted when ethylene was scrubbed from some atmospheres. It was suggested that improved visual colour, appearance and flavour and increased marketable yield justified the use of 4% CO₂ in storage (Smith and Reyes 1988). The cultivar Utah stored at 0–1 °C in 1.5% O₂ had better marketable quality after 11 weeks than those stored in air. Marketable level was improved by using 2.5–7.5% CO₂ in the storage atmosphere but not by 2–4% CO₂ (Reyes and Smith 1987).

CA storage was shown to affect disease development. At 1 °C, the growth *in vitro* of *Sclerotinia sclerotiorum* on celery extract agar was most suppressed in a storage atmosphere containing 7.5% CO₂ + 1.5% O₂, but only slightly suppressed in 4% CO₂ + 1.5% O₂ or in 1.5% O₂ alone compared with air. Watery soft rot caused by *S. sclerotiorum* was severe on celery stored in air for 2 weeks at 8 °C. A comparable level of severity took 10 weeks to develop at 1 °C. At 8 °C suppression of this disease was greatest in atmospheres of 7.5–30% CO₂ + 1.5% O₂, but only slightly reduced in 4–16% CO₂ + 1.5% O₂ or in 1.5–6% O₂ alone (Reyes 1988). A combination of 1 or 2% O₂ + 2 or 4% CO₂ prevented black stem development during storage (Smith and Reyes 1988). Decay was most severe on celery stored in 21% O₂ compared to controlled atmosphere storage. *Botrytis cinerea* and *S. sclerotiorum* were isolated most frequently from decayed celery (Reyes and Smith 1987). After storage at 1 °C celery grown in Ontario in Canada developed a black discolouration of the stalks which appeared outwardly in a striped pattern along the vascular strands. In cross section the vascular strands were discoloured and appeared blackened. A CA atmosphere of 3% O₂ + 2% CO₂ almost completely eliminated the disorder. Ethylene and prestorage treatment with sodium hypochlorite had little or no influence on the occurrence of the disorder but there was some indication of difference in cultivar susceptibility (Walsh *et al.* 1985).

Modified atmosphere packaging

The equilibrium atmospheres within OPP and LDPE bags containing celery were reached after 10 days and were 8–9% O₂ + 7% CO₂ for those in OPP bags and 8% O₂ + 5% CO₂ for those in LDPE bags (Gomez and Artes 2004). The celery stored in OPP bags was rated to have an appearance most similar to that at harvest. Rizzo and Muratore (2009) found that the most suitable modified atmosphere packaging was polyolefin film (co-extruded PE and PP) with an antifogging additive and storage at 4 ± 1°C and 90% r.h. for 35 days. They found tiny accumulations of condensate but it did not reduce shelf life. Gomez and Artes (2004) reported that decay developed in non-wrapped celery, but wrapping in either OPP- or LDPE-inhibited decay decreased the development of pithiness and retained the sensory quality, reducing both the development of the butt end cut browning and chlorophyll degradation.

Excessive water loss during storage can cause them to become tough so perforated PE film liners in crates or cartons can be used to minimize water loss (Lutz and Hardenburg 1968) as does other MA packages. Escalona *et al.* (2005) described an MA packaging for pallet loads by using a silicone membrane system for shipping celery to distant markets. The design of a system for 450 kg of celery per pallets was studied using an impermeable film with 0.2 and 0.3 dm² kg⁻¹ silicone membrane windows to reach an atmosphere of approximately 3–4% O₂ + 7–8% CO₂. Two kinds of silicone membrane windows were chosen with permeability ranges 4500–5250 ml O₂ dm² day⁻¹ and 10,125–14,000 ml CO₂ dm² day⁻¹. The storage conditions for a trial were 21 days at 5 °C and 95% r.h. followed by a shelf life in air of 2 days at 15 °C and 70% r.h. As a control, partially unsealed packages were used. Modified atmosphere packaging resulted in slightly better quality and lower decay than those in the control.

Chard

Chenopodiaceae

Beta vulgaris L. var. *cicla*. Other common names include: spinach beet, perpetual spinach, crab beet, seakale beet, Swiss chard and mangold. They are thought to have descended from *B. vulgaris* subspecies *maritima* and have been cultivated since

at least the 3rd century CE. It is a biennial plant that produces a rosette of leaves and a swollen tap root in the first year, which is a food store to produce the flowers in the second year. Some plants may produce flowers in the first year, which is called bolting. There are cultivars that have been specially selected to produce large quantities of leaf, which is the edible portion and little swollen root. They have shiny, green, ribbed leaves with petioles that may be white, yellow or red depending on the cultivar. The flavonoid content of fresh leaves of the cultivar Green was in the range 2.4–3.0 mg g⁻¹ f.w. The cultivar Yellow contained only flavone C-glycosides (2.1–2.3 mg g⁻¹ f.w.), while the flavonols were not detected. Their ascorbic acid content was between 0.4 and 0.5 mg g⁻¹ f.w. and after domestic storage a loss of 80% was observed (Gil *et al.* 1998). Comis (1989) reported that too much soil nitrogen can reduce the vitamin C content of Swiss Chard. The USDA nutritional database gave the following analysis 100 g⁻¹ fresh weight: energy 20 kcal, water 92.65 g, carbohydrates 4.13 g, sugars 1.1 g, fat 0.08 g, protein 1.88 g and dietary fibre 2.1 g. The chemical content was given by USDA Nutrient Database (2012a) in Table 48.

Table 48 The composition of chard for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.66 g	Thiamine	0.040 mg
Energy	19 kcal	Riboflavin	0.090 mg
Protein	1.80 g	Niacin	0.400 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.099 mg
Carbohydrate, by difference	3.74 g	Folate	14 µg_DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Sugars, total	1.10 g	Vitamin A	306 µg_RAE
Calcium	51 mg	Vitamin A	6116 IU
Iron	1.80 mg	Vitamin E (α-tocopherol)	1.89 mg
Magnesium	81 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	46 mg	Vitamin D	0 IU
Potassium	379 mg	Vitamin K (phylloquinone)	830.0 µg
Sodium	213 mg	Fatty acids, total saturated	0.030 g
Zinc	0.36 mg	Fatty acids, total monounsaturated	0.040 g
Total ascorbic acid	30.0 mg	Fatty acids, total polyunsaturated	0.070 g

Harvesting

They are harvested by hand by cutting the petioles just above the root. Harvest time is when the leaves are young and tender and before flowering.

Postharvest physiology

Ethylene production was $0.13\text{--}0.14\ \mu\text{l kg}^{-1}\text{ h}^{-1}$ at 20°C , but sensitivity is very high and exposure results in yellowing and senescence (Mencarelli 2002a). Respiration rate was given by Mencarelli (2002a) as $18\text{--}20\ \text{CO}_2\ \text{kg}^{-1}\text{ h}^{-1}$ at 2°C and $29\ \text{mg CO}_2\ \text{kg}^{-1}\text{ h}^{-1}$ at 20°C .

Storage

Leaf quality was unacceptable after 3 days of storage at 18°C , regardless of humidity level and during storage at 4°C and 43% r.h. they were unacceptable after 4 days of storage due to dehydration (Roura *et al.* 2000). Other storage recommendations were as follows:

- 0°C and 85–90% r.h. for 1–2 weeks (Lutz and Hardenburg 1968);
- 0°C and 95–100% r.h. for 10–14 days (SeaLand 1991);
- 8°C and 90–92% r.h. Waskar *et al.* (1998);
- 4°C and 86 or 98% r.h. remained acceptable for 9 days (Roura *et al.* 2000);
- 0°C and 95–98% r.h. for 1–2 weeks (Mencarelli 2002a).

CA storage can be effective and was shown to increase their postharvest life to 1 month at -0.5°C with $2\text{--}3\% \text{CO}_2 + 10\% \text{O}_2$ (Mencarelli 2002a).

Modified atmosphere packaging

Modified atmosphere packaging, with some 7% O_2 and 10% CO_2 , had no effect on total flavonoid content after 8 days of storage. Ascorbic acid content decreased, especially in Swiss chard, to reach levels below 50% of the initial content after 8 days of cold storage (Gil *et al.* 1998). Storage life was increased from 1 day at room temperature of $17\text{--}30^\circ\text{C}$ with 24–73% r.h. to 6 days in PE bags of $50\ \mu\text{m}$ with 2% ventilation (Waskar *et al.* 1998).

Diseases

The most frequent field pathogens that infect chard were reported to be *Peronospora schachtii* Fuckel and *Cercospora beticola* Sacc (Mencarelli 2002a).

Chavar

Zingiberaceae

Hitchenia caulina (Grah.) Baker synonymous with *Curcuma caulina* (Grah.) also called arrowroot lily, chowar and Indian arrowroot. The plant is native to India and is found mainly growing wild on the Mahabaleshwar plateau and neighbouring regions in forest areas with a high annual rainfall. For optimum growth hot moist conditions are essential: rainfall of upwards of 5000 mm per annum characterizes its natural habitat, though it may be grown on the banks of irrigation canals. A tuberous herb with a leafy stem, 0.9–1.2 m high, with oblong-lanceolate, fibrous leaves 30–50 cm long and 7.5–10 cm broad. The yellow flowers, which possess a long peduncle, are borne on a central spike. Tubers are normally the size of an orange with white flesh and covered with fibrous roots (Kay 1987). The tubers have a starch content of about 13% (10.9–18.3%) on a fresh weight basis, 60% of which is very similar to that of arrowroot starch. For maximum yields the plants are grown for about 2 years and the tubers are harvested when they are 20–24 months old. The tubers are dug by hand then washed and the fibrous roots removed, after which the cleaned tubers are grated and the resultant pulp washed thoroughly, sieved and then re-washed and the starch allowed to settle out. It is then sun dried (Khairnar 1945).

Chayote

Cucurbitaceae

Sechium edule (Jacq.) Swartz. Other common names include christophine and chocho. It is indigenous to Central America and was a common vegetable of the Aztecs in Mexico prior to the Spanish conquest. Its closest wild relative, *S. compositum*, is from Mexico and Guatemala (Newstrom 1991). It is a monoecious perennial vine with furrowed stems and large tendrils produced in the leaf axils. The edible portion is the berry-like fruit that is called a pepo, of which the outer wall is the receptacle. It is usually pear shaped up to 20 cm long with a pale green skin and crisp white flesh containing one central flat seed that is up to 5 cm long. The chemical content was given by USDA Nutrient Database (2012a) in Table 49.

Table 49 The composition of chayote fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	94.24 g	Thiamine	0.025 mg
Energy	19 kcal	Riboflavin	0.029 mg
Protein	0.82 g	Niacin	0.470 mg
Total lipid (fat)	0.13 g	Vitamin B-6	0.076 mg
Carbohydrate, by difference	4.51 g	Folate	93 µg_DFE
Total dietary fibre	1.7 g	Vitamin B-12	0.00 µg
Sugars, total	1.66 g	Vitamin A	0 µg_RAE
Calcium	17 mg	Vitamin A	0 IU
Iron	0.34 mg	Vitamin E	0.12 mg
		(α-tocopherol)	
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	18 mg	Vitamin D	0 IU
Potassium	125 mg	Vitamin K	4.1 µg
		(phyllloquinone)	
Sodium	2 mg	Fatty acids, total saturated	0.028 g
Zinc	0.74 mg	Fatty acids, total monounsaturated	0.010 g
Total ascorbic acid	7.7 mg	Fatty acids, total polyunsaturated	0.057 g

Harvesting and handling

This is when the fruit reach an acceptable size, but before the seed begins to emerge from the apex of the fruit and germinates (Figure 27), because when this occurs the fruit is unpalatable and the flesh can be tough. If there is any indication of the fruit splitting



Figure 27 Chocho (*Sechium edule*) from Jamaica on arrival in the United Kingdom showing germination of the seed.

then they are too mature to harvest and should be removed from the vine and discarded. Gautam and Sharma (1995) recommended harvesting 25–30 days after anthesis because sprouting was the most serious problem especially in fruits harvested 35 days after anthesis but it was less of a problem when harvested 25 days after anthesis. P Treatment with 1-MCP may be effective in delaying postharvest seed germination. Cadena-Iñiguez *et al.* (2006) found that after storage at 10 °C for 28 days 50% of the fruit had germinated 6 days after having been removed, whereas only 20% of the fruit that had been treated with 1-MCP germinated. Wiendl *et al.* (1997) reported that irradiation with 50 Gy of cobalt-60 on fruits wrapped in PE film and stored at 12–13.5 °C and 45–55% r.h had a storage life of 63 days.

Postharvest physiology

Cadena-Iñiguez *et al.* (2006) found that they had low respiration rate and ethylene production. Aung *et al.* (2004) hypothesized that gibberellins were essential in initiating chayote sprout development. They found that exogenous application of GA₁ and GA₃ of 1 mM (equivalent to 138 µg fruit⁻¹) promoted sprouting, while the gibberellin inhibitor, 1-mM tet-cyclacis (equivalent to 105.6 µg fruit⁻¹), inhibited sprout development. 1 mM prohexadione also inhibited sprout emergence in semi-mature fruits and retarded the development of emergent sprouts in mature fruits. They concluded that the promotive action of GA₁ and GA₃, and the inhibitory action of gibberellin antagonists supported the view that gibberellins play an essential role in chayote sprout development.

Storage

Cadena-Iñiguez *et al.* (2006) found that storage below 10 °C resulted in chilling injury. Chilling injury results in swollen, watery looking spots formed on the periderm. However, refrigerated storage recommendations were as follows:

- 7.2 °C for 3 weeks (Wardlaw 1937);
- 7.2 °C and 85–90% r.h. for 4–6 weeks with 4.9% loss (Pantastico 1975);
- 6 °C and 85–90% r.h. for 30 days (Tindall 1983);
- 7.2 °C and 85–90% r.h. for 8–10 days (SeaLand 1991);

- 9–11 °C and 85–90% r.h. for 4–6 weeks (Snowdon 1991);
- 7.5 °C (Gautam and Sharma 1995);
- 10 °C and 85% r.h. for 10 days followed by 4 days at ambient conditions (Marin-Thiele *et al.* 2000).

Transport

After 9 days of transport at 13–14 °C from Puerto Rico to the US fruits were generally in good condition with some mould growth, which was identified as *Mycospharella citrullina*. Rotting developed during subsequent marketing to levels that made many of the fruits unmarketable (Burton 1970). In a study of fruit exported to the United Kingdom from Jamaica shipped at 13 °C for some 10 days, 78% were sound, 16% had protruding seeds and 6% had fungal rots (Thompson *et al.* 1979).

Diseases

Juárez Merlín *et al.* (2007) identified five postharvest diseases: blister caused by *Colletotrichum gloeosporioides*, anthracnose caused by *C. orbiculare*, reddish-purple mould provoked by *Fusarium oxysporum*, white mould provoked by *Phytophthora capsici* and acid rot caused by *Geotrichum* sp. They found that hot water treatment (50 ± 1 °C) plus 1.5% chlorine for 30 s inhibited the development of these infections.

Cherenga kanda

Dioscoreaceae

Dioscorea wallichii Hook. Other common names include cheranga, kulu, ho and tungam sanga. It is distributed from India to China and Peninsula Malaysia, Assam, Bangladesh, Myanmar and Thailand from sea level up to 1300 m. Tubers are eaten after boiling and thoroughly washing. It is a climbing tuber bearing vine that grows on various large shrubs or trees in mixed deciduous forests, mountain slopes and in disturbed areas along roadsides and margins of cultivations. Shajeela *et al.* (2011) gave the composition of *D. wallichii* tubers as starch 59.30 ± 0.24 g 100 g⁻¹, niacin 52.40 ± 0.37 g 100 g⁻¹, ascorbic acid 88.30 ± 0.29 g 100 g⁻¹, *in vitro* protein digestibility (%) 4.31 and *in vitro* starch digestibility

49.36 where 1 unit = mg reducing groups 1 h g⁻¹ sample. Shajeela *et al.* (2011) also gave the following analysis for anti-nutritional factors: total free phenolics 0.33 ± 0.02 g 100 g⁻¹, tannins 0.04 ± 0.02 g 100 g⁻¹, hydrogen cyanide 0.16 ± 0.05 mg 100 g⁻¹, total oxalate 0.26 ± 0.01 g 100 g⁻¹, amylase inhibitor 5.27 AIU mg⁻¹ soluble starch and trypsin inhibitor 2.48 ± 0.07 TIU mg⁻¹ protein.

Chestnut

Fagaceae

Castanea spp. There are several species and hybrids including

- American chestnut *Castanea dentata* (Marsh.) Borkh originated in North America. American chestnut was devastated by chestnut blight caused by the fungus *Cryphonectria parasitica* at the beginning of the 20th century. The fungus infects stem tissues and kills the trees by girdling them.
- Chinese chestnut *C. mollissima* Mill. synonymous with *C. mollissima* Blume, *C. bungeana* Blume, *C. duclouxii* Dode, *C. fargesii* Dode, *C. formosana* (Hayata) Hayata, *C. hupehensis* Dode, *C. mollissima* var. *pendula* X. Y. Zhou & Z. D. Zhou, *C. sativa* Miller var. *formosana* Hayata, *C. sativa* var. *mollissima* (Blume) Pampanini, *C. vulgaris* Lamarck var. *yunnanensis* Franchet. The Chinese chestnut is cultivated in its native China and Korea. It grows close to sea level in the north of its range and at altitudes of up to 2800 m in the south of the range. It is a large tree that readily cross-pollinates with other species of chestnut including *C. crenata*, *C. dentata* and *C. sativa* to form hybrids (Sisco *et al.* 2005).
- European chestnut is *C. sativa* Mill. also called sweet chestnut, Spanish chestnut and Portuguese chestnut. The European chestnut is a large tree native to hilly areas of southern Europe where it has been cultivated for centuries.
- Japanese chestnut is *C. crenata* Siebold. & Zucc. synonymous with *C. japonica* Blume. The Japanese chestnut is native to southern Korea, has been cultivated in Japan for at least 3000 years and perhaps as many as 7000 years.

The fruit is an achene with cream-coloured starchy cotyledons covered with an astringent membrane called the pellicle or testa, which is protected by a spiny burr. As the fruit matures the burr changes

colour from green to brown and breaks in 2–4 length lines releasing the nuts. Sometime the burr splits on the tree but more often it opens after it has fallen. The nuts have a dormancy period during which they will not germinate, which is prolonged when the temperature is low. Mencarelli (2001) reported that their edible portion was 69% and that they are rich in sugars, mainly sucrose, glucose and fructose as well as fibre and potassium. He also commented that they are the only nuts that contain vitamin C, with about 40 mg 100 g⁻¹ of fresh raw product, but vitamin C decreased by about 40% after heating. Their chemical content was given in Table 50 and by USDA Nutrient Database (2012a) in Table 51. Total world production of chestnuts in 2010 was estimated by FAO (2012) as 1,944,996 tonnes.

Postharvest physiology

Respiration rate of *C. crenata* was 5–7 mg CO₂ kg⁻¹ h⁻¹ at 0 °C and 15–20 mg CO₂ kg⁻¹ h⁻¹ at 20 °C

Table 50 The composition of chestnut in China for 100 g⁻¹ fresh weight (source: adapted from Mencarelli 2001)

Water	41.0 g	Sodium	11 mg
Energy	189 kcal	Potassium	500 mg
Proteins	3.5 g	Iron	1.2 mg
Lipids	1.8 g	Calcium	38 mg
Starch	34.3 g	Phosphorus	89 mg
Sugars	8.1 g	Thiamine	0.22 mg
Fibre	8.4 g	Riboflavin	0.35 mg
		Niacin	1.4 mg

Table 51 The composition of raw, peeled chestnuts for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Energy	820 kJ	Vitamin B6	0.352 mg
Carbohydrates	44 g	Folate (vitamin B9)	58 µg
Sugars	11 g	Vitamin B12	0 µg
Fat	1.3 g	Vitamin C	40.2 mg
Protein	1.6 g	Calcium	19 mg
Water	60.21 g	Iron	0.94 mg
Vitamin A equiv.	1 µg	Magnesium	30 mg
Thiamine (vitamin B1)	0.144 mg	Phosphorus	38 mg
Riboflavin (vitamin B2)	0.016 mg	Potassium	484 mg
Niacin (vitamin B3)	1.102 mg	Sodium	2 mg
		Zinc	0.49 mg

while ethylene production rates were 0.001 at 0 °C and 0.01 at 20 °C ml kg⁻¹ h⁻¹ (Mencarelli 2001). Respiration rate of *C. mollissima* was reduced to a steady low level at 0–5 °C but was not further reduced by decreasing O₂ or increasing CO₂ in the atmosphere (Wang *et al.* 2000). The decay rate when exposed to 40% CO₂ for 20 days was only 1% after subsequent cold storage for 120 days but an off-flavour was detected when treated for more than 20 days. Also there were no adverse effects of any CO₂ concentrations tested if the treatment duration was not more than 10 days. The presence of an off-flavour was irreversible when the CO₂ concentration was greater than 50% and treatment duration was longer than 20 days (Liang *et al.* 2004).

Harvesting

If they are harvested about 1 week before they would normally drop, they may be difficult to remove from the burrs and may be smaller and softer in texture. They should not be picked or shaken from the tree until the burrs begin to split with the highest quality and yield result from promptly harvesting naturally fallen chestnuts (Miller 2006).

Curing

Mignani and Vercesi (2003) described curing the fruit directly after harvest to reduce postharvest losses. However, curing may result in a fermented flavour that diminished after several days or weeks' storage. The purpose is to rehydrate the kernels, kill weevils and reduce fungal damage. The reduction in fungi may be attributed to directly killing the fungi or encouragement of antagonistic yeasts. This could be achieved by holding chestnuts under water at ambient temperatures of approximately 15 °C for 3–9 days until fermentation started. This was judged when bubbles were given off. Another method was to place the nuts in water at 50–70 °C for 30–45 min. A postharvest hot water immersion at 50 °C for 10 min can be used to control chestnut weevils (*Curculio* spp.) (Miller 2006). Botondi *et al.* (2009) reported that curing of *C. sativa* by the immersion in water is traditionally carried out prior to storage in Italy. They tested various variables on the cultivar Marrone Fiorentino and found that immersion time in water must be at least 5 days and no longer than 7 days

in order to avoid cell destruction. A ratio of water to marron of 1:1 was optimum. After curing they were stored at room temperature of about 20 °C and 90% r.h. for 1 week and then at 0 °C and 90% r.h. for 2 months. They reported that TSS, ethanol, acetaldehyde and polyphenols did not change during storage.

Postharvest physiology

Chestnuts produce very little ethylene varying between 5 and 20 mg kg⁻¹ h⁻¹ depending on the temperature, also their respiration rate is low (Mencarelli 2001). Respiration rate was given as 2.5–3.5 ml at 0 °C and 7.5–10.0 ml CO₂ kg⁻¹ h⁻¹ at 20 °C. Rates of ethylene production were less than 0.01 µl kg⁻¹ h⁻¹ at 20 °C. Preharvest or postharvest exposure of burrs to 50–100 ppm ethylene or 500–1000 ppm Ethephon accelerated dehiscence (Kader 2003).

Storage

The freezing point of kernels is about –3 °C depending on cultivar and therefore the optimum storage temperature was given as –2 °C by Morris (2006) since they must not be allowed to freeze. At harvest nuts have some 50% moisture content and if this falls to about 35% they lose their viability and the kernels begins to shrink away from the shell (Miller 2006). Fresh chestnuts contained some 52% water by weight, which will change during storage. They were shown to lose some 1% in weight in 1 day at 20 °C and 70% r.h. (Mencarelli 2001).

Controlled atmosphere storage

Mignani and Vercesi (2003) recommended –2 to –1 °C in combination with greater than 10% CO₂ + less than 5% O₂. Storage of the *C. mollissima* cultivar Dahongpao at 0 °C in 0–5% O₂ for up to 120 days showed that off-flavours were produced by exposure to concentrations below 2% O₂ for 20 days or more. Storage in 0–2% O₂ could stimulate the decomposition of starch, while in 3–5% O₂ the decomposition rate could be slowed. Those exposed to 1–3% O₂ had higher total sugars compared to other treatments, but the mean decay rate in 0–2% O₂ was 10% and with those stored in air it was 7%.

The decay levels in 3–4% O₂ atmosphere for 20 days or 5% O₂ for 25 days were only 1% at the end of 120 days of cold storage. In general, 3% O₂ for 20 days was the best (Wang *et al.* 2004). The *C. sativa* cultivars Catot and Platella were stored at 1 °C in 20% CO₂ + 2% O₂ and their freshness, taste and flavour were maintained and after 105 days they looked as fresh and bright as those freshly harvested (Mignani and Vercesi 2003). This treatment controlled fungal infection except for those caused by *Aspergillus niger* but storage in 2.5% CO₂ + 1.5% O₂ was less effective. Rouves and Prunet (2002) found that the best storage conditions among cultivars that they tested Marigoule and Bouche de Betizac were –1 °C in 2% O₂ + 5% CO₂. There was ‘no water loss’ (*sic.*), mould development was much slower and taste remained unaltered but some germination occurred in Marigoule. Comballe and Marron de Goujonac did not store well in any of the conditions they tested.

Modified atmosphere packaging

MA packaging at an equilibrium gas content of greater than 15% CO₂ and less than 5% O₂ was used to minimize rots during storage and also preventing weight loss by Morris (2006). He also described the CALM system with the set point at –3 °C because the temperature inside the plastic was about 1 °C above that in the cool room. It was reported by Lee *et al.* (1983) that the best storage results for the *C. crenata* cultivar Okkwang were obtained when they were sealed in 0.1 mm PE bags (30 × 40 cm) with 9–11 pin holes. The total weight loss was less than 20% after 8 months of storage and the CO₂ concentration in the bags increased to 5–7% and the O₂ concentration was reduced to 7–9%. Panagou *et al.* (2006) showed that the atmosphere at equilibrium was 10.5% O₂ + 10.9% CO₂ for 12 µm microperforated PET/PE permeable and 40 µm microperforated film at 0 °C and 8.3% O₂ + 12% CO₂ at 8 °C. The total storage period was 110 days and sucrose content increased during the first 40 days in both films, but changed only slightly thereafter, but starch and ascorbic acid decreased throughout the storage period. In some less permeable film packages the O₂ concentration fell below 2% resulting in the development of off-odours. To create different O₂ and CO₂ compositions Homma

et al. (2008) stored chestnuts in one, two, or five layers of PE bags. The proportion of sound chestnuts decreased for all treatments after 2 months and starch breakdown was high in one or two layers of PE bag but was decreased when five layers of PE bag were used.

Diseases

Mignani and Vercesi (2003) reported postharvest infections with *Aspergillus niger*. Miller (2006) found that the most common storage diseases were caused by *Penicillium* spp. and *Fusarium* spp. resulting in a few dark spots on the kernel surface to complete decay of the kernel. Mouldy chestnuts were found to contain tremogens, zearalenone, T-2 toxin, vomitoxin and fumonisin B1 detected at low levels and only in very mouldy kernels. No aflatoxin was detected probably because aflatoxin is produced under warm conditions.

Chinese artichokes

Lamiaceae

Stachys affinis Bunge, synonymous with *S. tuberosifera* Naudin and *S. sieboldii* Miq. Other common names include chorogi, knotroot, artichoke betony and crosne. They originated in eastern Asia. The flavour of the tubers is a delicate nutty, artichoke-like flavour and is used as a cooked vegetable or raw in salads. Tubers quickly discolour when exposed to the air and are said to lose their flavour if they are peeled. In China, the tubers are used primarily for pickling and it is a part of *osechi*, which is cooked for celebrating the New Year in Japan. It is an herbaceous perennial plant growing up to 0.5 m that develops many underground stolons, the ends of which swell to form the brownish tubers. The tubers are small, convoluted with ridges running horizontally around them to give them a screw-like appearance. They are about 5–8 cm long and 2 cm wide. The skin is thin and brownish white or ivory white in colour and the flesh is white and tender. It is best to harvest them as required since their shelf life at 20 °C and 60% r.h. was shown to be only 1 or 2 days (Mercantilia 1989). Storage recommendations were 0 °C and 95% r.h. for 1–2 weeks (Mercantilia 1989, SeaLand 1991).

Chicory

Asteraceae, Compositae

Cichorium intybus L. synonymous with *C. intybus* var. *foliosum* Hegi. and *C. intybus* var. *sativum* (Bisch.) Janch. Other common names include endive, escarole, whitloof, witloof chicory and radicchio. It is sometimes confused with endive (*C. endiva*). It is native from western Asia to Europe and Central Russia. Its leaves have been used from ancient times in salads, and it was cultivated in Greek and Roman times. The edible portion of the salad chicory cultivars is the leaves (Figure 28), which are grown in the dark from the swollen taproot so that they are blanched. The blanched hearts are also used as a cooked vegetable. In Europe the plants are grown from seed and lifted from the ground in the autumn. The leaves are cut-off 2 or 3 cm above the root and the crowns are covered with soil or sand and placed in heated sheds or greenhouses. The new young growth within the covering is shielded from the light and is therefore blanched. The blanching makes them less bitter. The large roots, which when dried, roasted and ground can be blended with coffee or be used alone as an ersatz coffee. It is a perennial herb of the about 1 m high with bright blue flowers. It produces a long thick taproot. Curled chicory will freeze at about –0.8 to –0.6 °C (Wright 1942). The chemical content was given by USDA Nutrient Database (2012a) in



Figure 28 Chicory in a whole sale market in London in the United Kingdom.

Table 52 The composition of chicory for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Chicory whitloof	Chicory greens	Chicory roots
Water (g)	94.52	92.00	80.00
Energy (kcal)	17	23	72
Protein (g)	0.90	1.70	1.40
Total lipid (fat) (g)	0.10	0.30	0.20
Carbohydrate, by difference (g)	4.00	4.70	17.51
Total dietary fibre (g)	3.1	4.0	1.5
Calcium (g)	19	0.70	8.73
Iron (mg)	0.24	100	41
Magnesium (mg)	10	0.90	0.80
Phosphorus (mg)	26	30	22
Potassium (mg)	211	47	61
Sodium (mg)	2	420	290
Zinc (mg)	0.16	45	50
Total ascorbic acid (mg)	2.8	0.42	0.33
Thiamine (mg)	0.062	24.0	5.0
Riboflavin (mg)	0.027	0.060	0.040
Niacin (mg)	0.160	0.100	0.030
Vitamin B-6 (mg)	0.042	0.500	0.400
Folate (mg)	37	0.105	0.241
Vitamin B-12 (µg_DFE)	0.00	110	23
Vitamin A (µg)	1	0.00	0.00
Vitamin A (µg_RAE)	29	286	0
Vitamin D (D2 + D3) (IU)	0.0	5717	6
Vitamin D (mg)	0	2.26	0.0
Fatty acids, total saturated (µg)	0.024	0.0	0
Fatty acids, total monounsaturated (IU)	0.002	0	0.048
Fatty acids, total polyunsaturated (µg)	0.044	297.6	0.004

Table 52. Total world production of chicory roots in 2010 was estimated by FAO (2012) as 783,023 tonnes.

Harvesting and handling

François *et al.* (2009) evaluated the use of visible/near-infrared spectroscopy to determine the optimal harvesting date of chicory roots. The root harvest date, which resulted in the highest percentage of top quality chicory heads after forcing, was chosen as the optimal harvest date. Predicting the number of days before optimal root harvest was done reasonably accurately, with prediction errors of 8.86 days for the hybrid Mont Blanc and 10.61 days for the

Table 53 Respiration rate of chicory at different temperatures (source: adapted from Suslow and Cantwell 1999)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	6–10
6	10–16
7.5	23
25	45

hybrid Vintor. The visual part of the spectrum was not required in these calibration models. Pre-cooling is recommended to preserve their freshness and is achieved by top icing as soon as possible after harvesting (Wardlaw 1937).

Postharvest physiology

Chicory produces very low amounts of ethylene at 0.1–0.3 µl kg⁻¹ h⁻¹ at 0–6 °C and 0.6–1.0 µl kg⁻¹ h⁻¹ at 20 °C. Exposure to 10 µl L⁻¹ of ethylene for 6 days at 7.5 °C and 95% r.h. increased leaf browning, decay and pigmentation of midribs (Botondi *et al.* 1996, Suslow and Cantwell 1999). The respiration rate was given in Table 53.

Storage

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2 days (Mercantilia 1989, SPLFS 2001). They do not suffer from chilling injury but Botondi *et al.* (1996) found that there may be metabolic disorders after storage at 0 °C. Refrigerated storage recommendations were as follows:

- 0–1 °C and 85–95% r.h. for 2–3 weeks (Anonymous 1967);
- 0 °C for 20 days in plastic wraps or bags with the tops left open (Tindall 1983);
- 0 °C and 90–95% r.h. for 24 days (Mercantilia 1989);
- 4 °C for 12 days (Mercantilia 1989);
- 10 °C for 5 days (Mercantilia 1989);
- 0–1 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1991);
- 0 °C and 95–100% r.h. for 14–28 days (SeaLand 1991);
- 0 °C and 95–100% r.h. for 14–21 days for Raddichio (SeaLand 1991);

- -2 to -3 °C for 3 months by controlling decay (Bertolini and Pratella 1993);
- $3-5$ °C and 90% r.h. for 20–30 days. Cultivars that are whitened can only be stored 1–2 weeks under these conditions (Botondi *et al.* 1996);
- 6 °C for 11 days (Botondi *et al.* 1996);
- $0-1$ °C and 95–100% r.h. for 2–4 weeks (SPLFS 2001).

Controlled atmosphere storage

Storage of witloof leaves at 0 °C in 4–5% CO₂ + 3–4% O₂ delayed greening of the tips in light and delayed opening of the heads (Hardenburg *et al.* 1990). Saltveit (1989) also recommended 4–5% CO₂ and 3–4% O₂ but at 0–5 °C but it was reported to have had only a slight effect. Suslow and Cantwell (1999) recommended 3% O₂ + 5% CO₂. Storage in low O₂ atmospheres can promote internal browning. SPLFS (2001) recommended 2–3 °C and 95–100% r.h. 3–4 O₂ 4–5 CO₂ for 14–28 days but it had only a fair benefit. Storage at 5 °C in 10% O₂ + 10% CO₂ prevented red discolouration, leaf edge discolouration and other negative quality aspects, but in storage at 1 °C, there was increased red discolouration (Vanstreels *et al.* 2002). In a comparison of 5, 10, 15 and 20% CO₂ in storage at 0 °C Bertolini *et al.* (2003) found that 10% CO₂ was the most effective in suppressing *Botrytis cinerea* in red chicory. Later Bertolini *et al.* (2005) stored radicchio Rosso di Chioggia at 0 °C for up to 150 days. They artificially inoculated some heads with *B. cinerea* and found that lesion caused by *B. cinerea* decreased with increasing concentrations of CO₂ over the range 5–20% for up to 60 days. Subsequently only 10 and 15% CO₂ were effective, while after 120 days all the concentration had low efficacy. In naturally infected heads the effect of 5 and 10% CO₂ was effective in preventing *B. cinerea* even after 150 days of storage but it also reduced the fungus spreading to adjacent heads. Heads stored in 15% CO₂ for 150 days showed phytotoxic effects and increased vulnerability to rots. Monzini and Gorini (1974) recommended 0 °C in 1–5% CO₂ + 1–5% O₂ for 45–50 days. Velde and Hendrickx (2001) investigated storage of cut Belgian endive in atmospheres ranging from 2 to 18% CO₂ + 2–18% O₂ and found that the optimum concentration was 10% CO₂ + 10% O₂ + 80% N₂.

Atmospheres containing 25% CO₂ caused the central leaves to turn brown (Wardlaw 1937).

Physiological disorders

The margins of the leaves may turn yellow and become dry. The disorder is called marginal browning and is thought to be premature senescence caused by poor growing conditions or inappropriate transport or storage (Pantastico 1975).

Chillies

Solanaceae

Capsicum frutescens L. See also under capsicums for discussion on their taxonomy. Other common names include chilli, hot peppers, peppers, cherry peppers, Tabasco and bird chillies. It is native of tropical America and the Caribbean but is grown worldwide in tropical and warm temperate regions. Chillies are mainly used as flavouring of foods especially in Central America but they have also been used as a fungicide. For example Singh *et al.* (2011) found that alcohol extracts at 3000 µL L⁻¹ showed almost 100% inhibition of activity *in vitro* on *Penicillium digitatum*, *Aspergillus niger* and *Fusarium* sp. isolated from naturally infected citrus fruit. The fruit is a berry of extremely variable size, shape and colour, but usually shades of red orange and yellow when mature and are classified as non-climacteric (Bosland and Votava 2000). They are very pungent containing capsaicin (C₁₈H₂₇NO₃) in their placenta (Purseglove 1968). Cultivars vary from mild to very hot, which is determined by their capsaicin content. It is a bushy plant whose fruits are used fresh to flavour cooking either fresh or after they have been dried to extend their storage life. Total world production for chillies and green peppers in 2010 was estimated by FAO (2012) as 29,421,327 tonnes.

Harvesting and handling

Harvest maturity is based on colour and size and depends on variety and market requirements; some are harvested green and immature while others are harvested when they change from green to red, yellow or orange. Capsaicin content was found to be highest in fruit harvested at the initial colouring stage, followed by those of the reddening and greening stages.

Sugar content was higher in fruits of the initial colouring and reddening stages and lowest in those of the greening stage. Ascorbic acid content was highest in the reddening fruits followed by the initial colouring fruits and green fruits, while storage losses of ascorbic acid were higher in fruits of the greening stage than those of the colouring and reddening stages. During storage, the highest rates of ethylene production and respiration rate were in fruits harvested at the initial colouring stage followed by those fruits at the greening and reddening stages (Park *et al.* 2001).

Storage

Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2–3 days (Mercantilia 1989). Refrigerated storage recommendations were as follows:

- 0–4.4 °C for fresh fruit (Lutz and Hardenburg 1968);
- 0–10 °C with 60–70% r.h. for 6–9 months (Anonymous 1968, Lutz and Hardenburg 1968);
- 10 °C and 90% r.h. for 2–3 weeks (Mercantilia 1989);
- 7–10 °C and 90–95% r.h. for 1–3 weeks (Snowdon 1991);
- 10 °C and 90–95% r.h. for 14–21 days (SeaLand 1991);
- 5 or 10 °C for up to 60 days (Park *et al.* 2001).

Controlled atmosphere storage

Storage of green chillies for 6 weeks at 10 °C and 80–90% r.h. in 3% O₂ + 5% CO₂ resulted in less decay and wrinkling and they were firmer with higher TSS and vitamin C than those stored in air or other controlled atmospheres tested (Ullah Malik *et al.* 2009). Kader (1985, 1992) recommended 8–12 °C with 0% CO₂ and 3–5% O₂ which had a fair effect but was of no commercial use, but 10–15% CO₂ was beneficial at 5–8 °C. Saltveit (1989) recommended 12 °C with 0–5% CO₂ and 3–5% O₂ for the fresh market but controlled atmospheres had only a slight effect. For processing Saltveit (1989) recommended 5–10 °C with 10–20% CO₂ and 3–5% O₂ was recommended which had a moderate level of effect. Other CA storage recommendations include

- 10 °C and 90–95% r.h. with 0% CO₂ with 3–5% O₂ (SeaLand 1991).

- 3–5% O₂ retarded ripening and respiration rate and had a slight benefit on quality (González-Aguilar 2002).
- 10 °C and 5% CO₂ can cause calyx discolouration, skin pitting, discolouration and softening (González-Aguilar 2002).
- 10 °C and 80–90% r.h. in 3% O₂ + 5% CO₂ for 6 weeks (Ullah Malik *et al.* 2009).

Before processing, chillies can be stored under 3–5% O₂ + 15–20% CO₂ for up to 3 weeks at 5 °C without appreciable chilling injury or quality loss (González-Aguilar 2002).

Modified atmosphere packaging

Fresh chillies are often marketed in modified atmosphere packaging. The cultivar Nok-Kwang fruits were sealed in 25 µm PE film and stored at 18 or 8 °C. At both temperatures PE film reduced the weight loss below 1% and increased CO₂ concentration to 2–5% (Eum and Lee 2003). Amjad *et al.* (2009) found that the optimum thickness of PE film for maximum storage life was 15 µm at 7 °C and in these conditions they could be stored for up to 10 days.

Disease

Prasad *et al.* (2000) collected fruit from different parts of India that exhibited varying degrees of decay, discolouration and breaking of the pericarp, detachment of the pedicel and spore dust formation within the fruit. Altogether 67 types of fungi were isolated from the stored chilli fruits, 3 species of *Phycomycotina*, 11 species of *Ascomycotina* and 53 of *Deuteromycotina*. *Aspergillus flavus*, *A. terreus*, *A. candidus*, *A. niger*, *A. sclerotiorum*, *Fusarium moniliforme* [*Gibberella fujikuroi*], *F. sporotrichioides*, *Syncephalastrum racemosum*, *Paecilomyces varioti* and *Penicillium corylophilum* were commonly associated with decaying fruits stored in humid regions. Prasad *et al.* (2000) also found that capsaicin content was decreased due to fungal infection.

Chinese cabbage

Brassicaceae, Cruciferae

Linneas named Chinese cabbage as *Brassica chinensis* L. but in 1860 it was named *B. pekinensis* (Lour) Rupr.,

in 1954 it was *B. campestris* L. subspecies *pekinensis* (Lour) Olssen and in 1986 it was *B. rapa* subspecies *pekinensis* (Lour) Hanelt. *B. campestris* L. subspecies *chinensis* is also known as bok choy, Chinese chard, boy-toyo, pak-choy and pak-tsoi. Chinese cabbage is also classified morphologically as non-headed, half headed and completely headed types (Dixon 2007). Dixon (2007) reported that their origins may have been from natural crossing with pak choi and turnip (*B. rapa*). Pak choi has been cultivated in southern China for more than 1600 years. During the past 600 years variation has derived from Korea in the 13th century, countries of southern Asia in the 15th century and Japan in the 19th century. The edible portion is the broad basal shiny leaves that are up to 50 cm long with white midribs. They are formed in a rosette that grows into a compact head. There are many different cultivars varying from those with long slender heads with broad leaf stalks and the heads are quite open, to those with round heads with crimped light green leaves that have narrow ribs and closed heads.

Harvesting and handling

Harvesting is when the head is fully formed, but before the flower stem begins to emerge. They are cut directly below the lowest leaves. Damaged and infected leaves should be removed at harvest and the Chinese cabbage should not be exposed to direct sunlight. Forced-air cooling with high humidity was the most acceptable method of pre-cooling, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling less suitable (MAFF n.d.).

Storage

Postharvest losses over a storage period were compared between the traditional method of storing Chinese cabbage in clamps with a modified store where ventilation and air circulation were improved. Results clearly indicate that there are distinct advantages in improved ventilation (Table 54). Storage at 10 °C for 2 weeks in 100 µL L⁻¹ ethylene compared to ethylene free air resulted in a higher level of leaf abscission (Wang 1985). Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2 days (Mercantilia 1989).

Table 54 The effect of storage method on the postharvest losses of cabbages over 120 days in China (source: adapted from Li and Huang 1992)

Type of loss	Traditional method (%)	Improved storage (%)
Trimming	10–15	10–15
Weight loss	7–12	3–7
Rejects	15–20	5–8
Total	32–47	18–30

Refrigerated storage recommendations were as follows:

- 0 °C and 90–95% r.h. for 1–2 months (Lutz and Hardenburg 1968);
- 0 °C for 30–40 days (Tindall 1983);
- 0–1 °C for up to 6 weeks (Mertens 1985);
- 0 °C and 90–95% r.h. for 24 days (Mercantilia 1989);
- 4 °C for 15 days (Mercantilia 1989);
- 8 °C for 10 days (Mercantilia 1989);
- 0 °C and 95–100% r.h. for 2–3 months (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 30–60 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 1–2 months (Snowdon 1991).

Controlled atmosphere storage

Pelleboer and Schouten (1984) reported that after 4 months of storage of the cultivars Chiko and WR 60 at 2–3 °C in 0.5% CO₂ + 3% O₂ or less, the average percentage of healthy heads was 72%, and after 5 months, 60% or more were healthy. After subsequent storage at 15 °C and 85% r.h. to simulate shelf life the corresponding percentages were 58 and 43%. Following storage in 6% CO₂ + 3% O₂ or 6% CO₂ + 15% O₂ there was a rapid fall in quality, confirming that 6% CO₂ could be harmful. Wang and Kramer (1989) showed that storage in 1% O₂ extended their postharvest life and reduced the decline in ascorbic acid, chlorophyll and sugars in the outer leaf laminae. Apeland (1985) stored the cultivars Tip Top and Treasure Island at 2.5 or 5.0 °C in 0.5, 2.5 or 5.0% CO₂ + 1–20.5% O₂. With Tip Top the storage was best at 5 °C in 5% CO₂ + 5% O₂. The results with Treasure Island were inconclusive because the control heads kept very well but with an average of only 68% saleable after 120 days. Other storage recommendations were as follows:

- 1% O₂ was shown to extend its storage life and reduce the decline in ascorbic acid, chlorophyll and sugar content in the outer leaf lamina (Chien and Kramer 1989).
- 0–5 °C with 0–5% CO₂ and 1–2% O₂ had only a slight effect (Saltveit 1989).
- 0 °C with 1% O₂ (Hardenburg *et al.* 1990).

CA storage has been shown to influence disease development. Hermansen and Hoftun (2005) inoculated the cultivar Nerva with *Phytophthora brassicae* and stored them at 1.5 °C in air, 0.5% CO₂ + 1.5% O₂ or 3.0% CO₂ + 3.0% CO₂ for 94–97 days. The infection caused by *P. brassicae* was significantly higher in both the controlled atmosphere storage treatments than in air, but *in vitro* studies gave the opposite results. CA storage can affect physiological disorders. Brown midribs, spots or streaks of brown tissue of the leaves and midribs, pepper spots are common physiological disorders. Chilling injury (brown midribs) found in Parkin was highest in heads stored in air. Controlled atmosphere storage reduced this disorder and the lowest percentage of brown midribs was found in 3% CO₂ + 3% O₂. No chilling injury was found (Hermansen and Hoftun 2005). Adamicki (2003), working with the F₁ hybrid cultivars Asten, Bilko, Gold Rush, Maxim, Morillo, Parkin and RS 6064, also reported that low concentrations of O₂ and CO₂ greatly reduced the incidence of physiological disorders including brown ribs. However, storage at 5% CO₂ + 3% O₂ resulted in lower percentage of marketable heads and higher percentage of damaged leaves and heads compared to storage in air for 100–130 days at 0, 2 or 5 °C and 95–98% r.h. CO₂ concentrations greater than 5% resulted in greater losses of weight and trim, caused mainly by leaf rotting (Adamicki and Gajewski 1999). They also found that 1.5–3.0% O₂ + 2.5% CO₂ was the best atmosphere for long-term storage. For most of the F₁ cultivars tested a storage temperature 2 °C was better than 0 °C.

Chinese kale

Brassicaceae, Cruciferae

Brassica alboglabra Bailey, it is also simply called kale. The edible part is the leaves that are large and borne on an erect stem. Most types have smooth leaves,

but curly cultivars are cultivated. The kale grown in Europe is *B. oleracea* var. *acephala* and is used mainly as fodder but is sometimes used as a substitute for cabbage. Respiration rate and ethylene production for Chinese kale reached a peak after 6 days when stored at 20 °C (Wu *et al.* 1995).

Chinese kale was treated 10 µl L⁻¹ of 1-MCP for 24 h, followed by storage for up to 7 days at 20 °C. 1-MCP treatment extended the shelf life, reduced weight loss and decreased the rate of softening and chlorophyll degradation. In addition the 1-MCP treatment reduced their respiration rate and ethylene production and postponed the decrease of ascorbic acid, carotenoids and glucosinolates (Bo Sun *et al.* 2012). Wang (2000) found that treatment of Chinese kale with moist air at 45 °C for 30 min resulted in better retention of postharvest quality, delayed yellowing and a lower decline in sugars and organic acids in storage at 15 °C compared to those that had not been treated. In Thailand they could be stored at room temperature of about 31 °C for only 2 days (Siriphan 1982). During storage at 0 °C reducing sugars and soluble protein content declined in both stems and leaves but increased in the flower buds. Peroxidase activity increased in all parts during storage and crude fibre content of the leaves also increased (Wu *et al.* 1995). It is not always clear exactly which kale is being referred to in the literature, but refrigerated storage recommendations were 0–1 °C and 95% r.h. for 2–4 weeks (Snowdon 1991) and 0 °C and 95–100% r.h. for 10–14 days (SeaLand 1991). Wrapping in them in wet newspaper and then placing them in plastic bags and storage at 0 °C gave the best qualities and longest storage life, which averaged about 16 days (Siriphan 1982).

Chinese potato

Labiatae, Lamiaceae

Solenostemon rotundifolius (Poir.) J.K. Morton, which is synonymous with *Coleus rotundifolius* Chev. and Perrot. Other common names include Hausa potato, coleus potato, Sudan potato and country potato. It is believed to have originated in Central Africa or East Africa, but from early times it has spread throughout tropical Africa and Asia. It is an important minor tuber crop cultivated in India, Sri Lanka, Malaysia, Indonesia and parts of Africa. In India, it

was reported to be grown in most of the homestead gardens of Tamil Nadu and Kerala. However, owing to its wide acceptance as an aromatic tuberous vegetable there is a gradual spread of the crop as an irrigated commercial crop and of late it has been intensely cultivated in more than 500 ha in south Tamil Nadu (Edison *et al.* 2006).

A small, herbaceous annual up to 30 cm high, prostrate or ascending, with a succulent stem and thick leaves having an aromatic smell resembling that of mint. Small dark-brown tubers are produced in clusters at the base of the stem (Kay 1987). In India two types are recognized: those having small-sized tubers with good flavour and others with large-sized tubers and higher yield. An improved cultivar, Sree Dhara, has been released in India with a yield potential is 20–25 tonnes ha⁻¹ (Pandey 2007). The composition of the tubers was quoted by Kay (1987) as water 75%, carbohydrate 21%, protein 1.4%, fat 0.5%, fibre 0.7%, calcium 17 mg 100 g⁻¹, iron 6 mg 100 g⁻¹, thiamine 0.05 mg 100 g⁻¹, riboflavin 0.02 mg 100 g⁻¹, niacin 1 mg 100 g⁻¹ and ascorbic acid 1 mg 100 g⁻¹. The principal amino acids were arginine, aspartic and glutamic acids. Pandey (2007) reported that tubers had 73% starch on dry weight basis, 1–1.5% protein on fresh weight basis or 7% on dry weight basis and are rich in minerals including calcium and iron and contain vitamins including thiamine, riboflavin, niacin and ascorbic acid.

Pandey (2007) reported that in India it is a short duration crop of 4 in 6 months. The tubers can be harvested when all leaves and stem begin to wither. The tubers are normally dug by hand and harvesting should not be delayed as the mature tubers decay rapidly when left in the soil. Kay (1987) also reported that the tubers are ready for harvesting when the leaves begin to wither and are normally dug by hand, but they can be stored successfully in dry sand or in a cool, well-ventilated shed.

Chinese water chestnut

Cyperaceae

Eleocharis dulcis (Burm. f.) Trin. ex Hensch. var. *tuberosa* (Schult.) Koyama synonymous with *E. tuberosa* Schult. Two very distinct forms of *E. dulcis* are recognized. One is a wild form, which generally grows in stagnant water, produces very small,

dark skinned, almost black secondary corms and is sometimes referred to in the literature as *E. plantaginea* or *E. plantaginoides*. The second form occurs only under cultivation and produces larger, sweeter, secondary corms and was originally described as a separate species *E. tuberosa* (Chen *et al.* 1945). Other common names include biqi, matai and water nut. It should not be confused with water chestnut (*Trapa natans*) which are grown for their seeds. It grows from sea level up to 1200 m and is wild in many parts of India, South East Asia and Polynesia. It is grown commercially in China, Japan, Hong Kong, the Philippines, India, Hawai'i and other Pacific islands.

It is an annual, aquatic, sedge plant which has no true leaves and photosynthesis is in the upright tubular septate stems. In China rhizomes spread from the base of the plant: the first appear 6–8 weeks after planting, grow horizontally under the surface of the soil, and then turn upwards to form suckers and ultimately daughter plants. Others, starting somewhat later, bend down and produce corms at the tip (one per rhizome), about 12 cm below the soil surface. The young corms are white, becoming scaly and brown when mature, subglobose and somewhat flattened (Chen *et al.* 1945). The corms are up to 4 cm in diameter and show considerable variation in composition. An approximate analysis of the edible portion of fresh corms was given by Kay (1987) as moisture 77.29%, protein 1.53%, fat 0.15%, nitrogen-free extract 18.9%, reducing sugars 1.94%, sucrose 6.35%, starch 7.34%, fibre 0.94%, ash 1.19%, calcium 2–10 mg 100 g⁻¹, iron 0.43–0.6 mg 100 g⁻¹, phosphorus 52.2–65 mg 100 g⁻¹, thiamine 0.24 mg 100 g⁻¹, riboflavin 0.007 mg 100 g⁻¹, niacin 0.94 mg 100 g⁻¹ and ascorbic acid 9.2 mg 100 g⁻¹. Kays and Sanchez (1985) reported that the principal sugars found in the corms at harvest were sucrose, which was over 90% of the total, glucose and fructose. The starch is similar to that obtained from sweet-potatoes or cassava and the pulp extracted from the corms has been shown to contain an antibiotic principle, designated puchiin (Chen *et al.* 1945). Peng and Jiang (2004) immersed slices of the cultivar Guilin in boiling water for 30 s and then placed them into film wrapped trays and stored them at 4 °C for 12 days. This treatment effectively prevented browning associated with phenylalanine ammonia lyase, PPO and peroxidase activities and total phenolic content

Table 55 The composition of Chinese water chestnut for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	73.46 g	Thiamine	0.140 mg
Energy	97 kcal	Riboflavin	0.200 mg
Protein	1.40 g	Niacin	1.000 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.328 mg
Carbohydrate, by difference	23.94 g	Folate	16 µg_DFE
Total dietary fibre	3.0 g	Vitamin B-12	0.00 µg
Sugars, total	4.80 g	Vitamin A	0 µg_RAE
Calcium	11 mg	Vitamin A	0 IU
Iron	0.06 mg	Vitamin E (α-tocopherol)	1.20 mg
Magnesium	22 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	63 mg	Vitamin D	0 IU
Potassium	584 mg	Vitamin K (phyloquinone)	0.3 µg
Sodium	14 mg	Fatty acids, total saturated	0.026 g
Zinc	0.50 mg	Fatty acids, total monounsaturated	0.002 g
Total ascorbic acid	4.0 mg	Fatty acids, total polyunsaturated	0.043 g

and delayed the decline in eating quality. The chemical content was given by USDA Nutrient Database (2012a) in Table 55.

In China the corms are usually ready for harvest 7–8 months after planting when the shoots have turned brown or have been killed by frost. The corms will turn a characteristic deep chestnut-brown colour by that time. They are usually dug out by hand although Kay (1987) indicated that in the United States the soil is carefully lifted onto a mesh screen and worked over with paddles or rubber pads to separate the corms from the soil. They may be harvested semi-mechanically by turning the soil over with a plough and collecting the corms from the surface by hand. In most areas irrigation is stopped at least 3–4 weeks before harvest so that the ground dries and the corms are carefully dug out by hand to avoid bruising.

After harvest corms rapidly decline in quality due to desiccation, discolouration and pathogen invasion (Kays and Sanchez 1985). At a temperature of about 14 °C sprouting occurs (Hodge and Bisset 1955). SeaLand (1991) recommended 4.4 °C and 85–90% r.h. for 100–128 days and Morton *et al.* (1988) recommended 1.1–4 °C for 6 months. In climates with moderate winter temperatures they can be stored

in the ground (Morton *et al.* 1988). Holding the corms at 1.5 °C in aerated aqueous solutions containing 10% sodium chloride at 6 months maintained visual quality, TSS and texture although the concentration of sucrose was reduced while fructose and glucose increased. In aqueous solutions alone storage losses due to desiccation were eliminated, but it resulted in permeation of sound corms with odoriferous metabolites from rotting corms within the container (Kays and Sanchez 1985). The sodium concentration within the tissues increased markedly but did not result in cellular death. However, it could not be sufficiently removed from unpeeled corms by passive diffusion prior to marketing. In the United States commercial supplies of the dried corms are usually packed in 64 L moisture proof containers, which are sealed but not airtight. They can be kept satisfactorily at temperatures between –1 and 4 °C for up to 6 months.

Chinese yam

Dioscoreaceae

Dioscorea opposita Thunb. is synonymous with *D. batatas* Decne., *D. decaisneana* Carr., *D. doryphora* Hance, *D. oppositifolia* L., *D. polystachya* Turcz., *D. potaninii* Prain & Burkill, *D. pseudobatatas* (Ham.) Hert., *D. rosthornii* Diels, *D. swinhoei* Rolfe. Other common names include common yam, Chinese potato, cinnamon vine, cinnamon yam, Korean yam, nagaimo, wild yam and yamswurzel. It is a native of China and is also widely grown in Japan, Korea, Taiwan and other colder climates in the Far East. It can tolerate colder temperatures than any other commercially produced yam (Purseglove 1972). It occurs naturally in forests, scrubland, sides of rivers, roadsides, hillsides and disturbed areas at elevations of 100–2500 m. In the mid-19th century it was cultivated experimentally in Europe as a substitute for potato (*Solanum tuberosum*). Chinese yam may be eaten raw which is an exception since most yams must be cooked before consumption due to harmful substances in the raw state. Unlike most other *Dioscorea* species, the tubers of *D. opposita* grown in Japan do not contain any sapogenins. In Japan the whole tubers are briefly soaked in a mixture of vinegar and water to neutralize oxalate crystals found in their skin. The tuber is starchy, bland and mucilaginous

when grated and is called tororo. The *tororo* may be mixed with other ingredients including wasabi (*Wasabia japonica*) and spring onions (*Allium cepa*).

It is a twining herbaceous vine that grows up to some 3 m long with cinnamon-scented flowers. It can produce different forms of underground erect tubers that are up to 1 m in length and have white flesh (Figure 29). In Japan they recognize three types that are called: naga-imo (long and cylindrical), icho-imo (palmate) and tsukune-imo (globular). Aerial tubers are also produced in the leaf axils. Flesh browning seems to be associated with phenolic amines (Kay 1987). Satoh and Tanabe (1971) also reported that stored tubers when cut or grated rapidly discoloured because of the presence of polyphenolic compounds. They suggested that field spraying with maleic hydrazide would suppress browning of the tubers. Kay (1987) gave a typical analysis of the edible portion of the tubers as 70–80% water, 16–29% carbohydrate (mainly starch), 1.11–3.1% protein, 0.06–1.1% fat, 0.33–1% fibre and 0.69–1.1% ash.

Harvest maturity is some 6 months after planting. They are dug from the soil, but *naga-imo* tubers are

difficult to harvest since they are long and cylindrical and may reach a depth of 1 m. Tubers are consumed mainly directly after harvest, but they are also stored over winter in clamps or cold stores in Japan (Kay 1987). Fully mature tubers can be stored at 5 °C for long periods of time and do not turn brown, even when subsequently stored at higher temperatures (Imakawa 1967). Ventilated storage at about 25 °C for up to 60 days can also be used (Tindall 1983, Opara 1999). Fully mature *D. opposita* tubers can be stored for long periods of time at low levels of O₂ at 5 °C, which was also shown to reduce browning of tubers (Imakawa 1967).

Choy sum

Brassicaceae, Cruciferae

Brassica rapa subsp. *parachinensis*. O'Hare *et al.* (2000) found that at retail temperatures shelf life can be severely curtailed because of leaf yellowing. O'Hare *et al.* (2012) reported that outer leaves, which showed signs of rotting after 14 days, and a combination of rotting and yellowing after 21 days contributing to 20 and 40% of product removal, respectively. They also reported that it contains high folate levels comparable to spinach and total folate activity remained significantly unchanged during 3 weeks of storage at 4 °C. O'Hare *et al.* (2000) recommended controlled atmosphere storage at 10 °C with 2% O₂ and 5% CO₂ that increased shelf life by 105% compared to cold storage alone.

Chufa

Cyperaceae

Cyperus esculentus L. Other common names include earth nut, tiger nut and yellow nutsedge. Chufa is thought to have originated in the Mediterranean area and western Asia but has spread (mainly as a weed) to many parts of the world. It will grow in a very wide range of climatic conditions and occurs in the tropics, subtropics and warm temperate regions. It is cultivated in several countries. The tubers are used as a foodstuff, particularly in Africa, where they are an important food crop with certain tribes. They may be eaten raw, baked as a vegetable, roasted or grated and used to make ice cream, sherbets or horchata, a



Figure 29 Nagaimo on sale in a California supermarket in 2008. See colour plate section.

milky white beverage. The tubers contain 20–28% of a yellow non-drying pleasantly flavoured oil, similar to olive or sweet almond oil. The oil is used in Spain and Italy for culinary purposes and for the manufacture of soap. Starch may be extracted after the oil has been removed from the tubers. It is an erect perennial, grass-like sedge, usually 30–90 cm high, with long narrow dark-green leaves arranged in three rows around the triangular stem. The plant develops as a series of shoots, bulbs and stem tubers connected by brown wiry rhizomes which are strengthened by lignification of the inner cortex. Tubers are borne at intervals along the rhizomes. Basal bulbs grow from rhizome tips, producing shoot growth and new plants. The plant, when growing wild, is extremely difficult to eradicate and is stated to be the 15th worst weed in the world. Tubers are normally 1.5–2 cm in length, with a maximum diameter of approximately 1–2 cm. They have very thin skins and the flesh is slightly yellowish-white in newly formed tubers, but darkens with increasing maturity; the flavour is sweet and nutty. Tubers contained 70–90% moisture. The average dry matter figures have been quoted as residual moisture 9.3%, protein 8.6%, fat 21.8%, carbohydrate 48%, ash 1.7%, magnesium 0.1 mg 100 g⁻¹, phosphorus 211.5 mg 100 g⁻¹ and potassium 0.5 mg 100 g⁻¹. The carbohydrate consisted of 33.4 g starch and 14.6 g total sugars (Kay 1987). In Turkey Coşkun *et al.* (2002) gave average dry matter analysis in gram per kilogram as 932.8 dry matter, 245.0 crude lipid, 256.8 starch, 14.3 ash, 50.5 protein, 89.1 crude fibre, 17.1 reducing sugar and 154.3 total sugar of which 130.4 g were sucrose.

The tubers are ready for harvesting when the plants begin to die back, which is usually in 3–4 months after planting. They are usually dug by hand or by running a small lifting plough under them and collected them into boxes or sacks. The entire plant is laid on the soil and allowed to dry for 1–3 days before the tubers are separated for storage in thin layers in sheds. They may also be washed in running water and then dried either in the sun or artificially, after which they are graded and stored. In Florida the negro bug, *Thyreocoris pulicaria*, has been reported to damage the crop. The larvae develop inside the tubers that can result in postharvest rotting but they are seldom seriously affected by diseases. Crop rotation is the best means of control.

Cinnamon yam

Dioscoreaceae

Dioscorea oppositifolia L. Tu (2002) mentioned that there is confusion regarding the correct taxonomy of *D. oppositifolia*. She claimed that *D. batatas* Decne is the most common synonym. Purseglove (1972) referred to *D. opposita* Thunb. as being synonymous with *D. batatas* and used the common name of Chinese yam but does not mention *D. oppositifolia*. Kay (1987) reported that *D. bulbifera* occurs in a wide variety of forms and many synonyms have appeared in the literature including *D. oppositifolia* Campbell. That is the only reference to *D. oppositifolia* in her book, but she deals in detail with *D. opposita* and gave its common names as Chinese yam, Chinese potato and cinnamon vine. Kay (1987) and Coursey (1967) do not give any alternative names for *D. opposita* and Coursey gives its common names as Chinese yam and cinnamon vine. He does not mention *D. oppositifolia* in his book. On this basis *D. opposita*, *D. oppositifolia* and *D. bulbifera* are dealt with separately in this book. Other synonyms include *D. cayenensis* Lam. var. *pseudobatatas* Hauman, *D. decaisneana* Carrière, *D. divaricata* Blanco, *D. doryphora* Hance, *D. opposita* Thunb., *D. oppositifolia* L. var. *linnaei* Prain & Burkill, *D. opposita* Thunb., *D. oppositifolia* L. var. *meeboldtii* Prain & Burkill, *D. oppositifolia* L. var. *thwaitesii* Prain & Burkill, *D. polystachya* Turcz., *D. potaninii* Prain & Burkill, *D. rosthornii* Diels, *D. swinhoei* Rolfe, *D. trinervia* Roxb. ex Prain & Burkill. In India it is called pit kanda since kanda is Hindi for yam.

It originated in China, India and Sri Lanka and was introduced into the United States where it has become an invasive species. Both the tuber and bulbils of *D. oppositifolia* are edible, although the bulbils are generally not collected or used as food. The tuber, which can weigh up to 2 kg or more if grown in deep loam soils, has a good flavour and is nutritious. The tuber is also used in Chinese medicine and is sometimes used as an herbal tonic (Tu 2002). It stimulates the stomach and spleen and has an effect on the lungs and kidneys. The tuber has been eaten for the treatment of poor appetite, chronic diarrhoea, asthma, dry coughs, frequent or uncontrollable urination, diabetes and emotional instability. Externally, the tuber has also been applied to ulcers, boils and abscesses. It contains allantoin, a cell-proliferant that speeds up the healing process. Tu (2002) stated that

the leaf juice from *D. oppositifolia* can be used to treat snake bites and scorpion stings. Its roots contain diosgenin, which is a compound often used in the manufacture of progesterone and other steroid drugs. It has also been used traditionally as a contraceptive and in the treatment of various disorders of the genitinary organs and for asthma and arthritis. It is frequently planted for its ornamental value. The flowers smell like cinnamon.

The species name *oppositifolia* refers to the opposite arrangement of its leaves while the species synonym sometimes used is *batatas* meaning potatoes (Bailey 1949). It is a perennial twining vine that has round slender stems. The tuber is cylindrical, up to about 1 m long and 7–8 cm in diameter, and has a brown smooth surface and white flesh and grows downwards. The vine produces bulbils in the leaf axes and each plant produces some 20 bulbils each year. The bulbils have been observed sprouting new shoots within 2 weeks of formation. It can be propagated both sexually from seeds and asexually by the bulbils (Tu 2002). *D. oppositifolia* is listed in the South East Exotic Pest Plant Council's Invasive Exotic Pest Plant List for Tennessee, USA, as a 'Rank 1 Severe Threat' species, indicating that it is an exotic species that possesses characteristics of an invasive species and could spread easily into native plant communities and displace native vegetation (Tu 2002).

The tuber contained about 20% starch, 75% water, 0.1% vitamin B1 and 10–15 mg vitamin C. It also contains mucilage, amylase, amino acids and glutamine (Tu 2002). Mohan and Kalidass (2010) gave the following analysis of the tuber per 100 g fresh weight: 78.49% moisture, 9.41 ± 0.04 starch, 7.00 ± 0.07 crude protein, 6.92 ± 0.11 crude lipid, 5.53 ± 0.13 crude fibre, 6.38 ± 0.12 ash, 74.17 nitrogen-free extractives, 18.82 ± 0.03 niacin, 26.23 ± 0.12 g ascorbic acid and 1616.42 g 100 g^{-1} calorific value (kJ 100 g^{-1} dry matter). They also gave *in vitro* protein digestibility as 5.29% and *in vitro* starch digestibility as 39.21%. Shajeela *et al.* (2011) gave the following analysis for *D. oppositifolia* var. *dukhumensis* as starch 52.24 ± 0.31 g 100 g^{-1} , niacin 37.14 ± 0.32 g 100 g^{-1} and ascorbic acid 96.42 ± 0.37 g 100 g^{-1} . For *D. oppositifolia* var. *oppositifolia* Shajeela *et al.* (2011) gave starch 46.04 ± 0.1 g 100 g^{-1} , niacin 54.30 ± 0.51 g 100 g^{-1} and ascorbic acid 90.51 ± 0.54 g 100 g^{-1} . *D. oppositifolia* also contains anti-nutritional factors identified

by Mohan and Kalidass (2010) per 100 g fresh weight as total free phenolics 0.28 ± 0.03 g, tannins 0.10 ± 0.04 g, hydrogen cyanide 0.14 ± 0.02 mg, total oxalate 0.38 ± 0.05 g, amylase inhibitor 4.13 AIU mg^{-1} soluble starch and trypsin inhibitor 2.1 TIU mg protein^{-1} . Shajeela *et al.* (2011) gave the following analysis for anti-nutritional factors: *D. oppositifolia* var. *dukhumensis* total free phenolics 0.36 ± 0.01 g 100 g^{-1} , tannins 0.24 ± 0.07 g 100 g^{-1} , hydrogen cyanide 0.24 ± 0.02 mg 100 g^{-1} , total oxalate 0.36 ± 0.01 g 100 g^{-1} , amylase inhibitor 2.46 AIU mg^{-1} soluble starch and trypsin inhibitor 13.30 ± 0.09 TIU mg^{-1} protein. For *D. oppositifolia* var. *oppositifolia* Shajeela *et al.* (2011) gave the following total free phenolics 0.56 ± 0.01 g 100 g^{-1} , tannins 0.36 ± 0.11 g 100 g^{-1} , hydrogen cyanide 0.33 ± 0.04 mg 100 g^{-1} , total oxalate 0.46 ± 0.07 g 100 g^{-1} , amylase inhibitor 2.10 AIU mg^{-1} soluble starch and trypsin inhibitor 11.26 ± 0.12 TIU mg^{-1} protein.

Coconut

Palmae

Cocos nucifera L. Other common names include water nuts, tender coconut and jelly coconuts. The main use of coconuts is the oil extracted from the copra of mature nuts, which has an oil content of 60–68% (Purseglove 1972). If harvested while still immature the fruit contains a jelly like lining (which is the developing copra) inside the hard shell and a liquid called coconut water or coconut milk. Purseglove (1972) reported that there was considerable controversy as to its origin, perhaps north western South America, and whether it can establish itself on suitable sites without the aid of man. Perhaps by diminution when coconuts fall into the sea and are washed up in remote beaches. The main edible portion is the nut, which is actually a fibrous drupe containing a thick brown dry outside layer consisting of a smooth exocarp, a fibrous mesocarp called coir and then an endocarp that is hard shell inside of which is the white flesh or copra containing the milk.

Harvesting and handling

After flowering the nut takes a long time to develop. For marketing as fresh nuts they are usually about



Figure 30 Jelly coconut ready for harvesting in Jamaica.

11 months old. Nuts are also harvested when they are immature, some 7 months old, when the copra is still a jelly and are called water nuts (Figure 30). At this stage the milk has the highest sugar content and they are used for drinking by cutting off the end and drinking the milk directly from the nut. In Thailand the outsides are trimmed into an attractive pattern and they are sold on the street. To prevent browning the trimmed nuts are dipped in 1–3% sodium metabisulphite solution for 2–5 min and then wrapped in plastic film and sometimes fungicide is included in the sulphite solution. With the sodium metabisulphite treatments they can be stored for up to 7 days while those without began to turn brown after 2 days (Tongdee *et al.* 1992). Mohpraman and Siriphanich (2012) reported that residues of sodium metabisulphite were found to be higher in younger fruit than in older ones. They found that the sodium metabisulphite solution penetrated the nut's interior via air channels in the husk and through the soft eye. To avoid residues in the edible portion they recommended using coconuts that are at least 6 months old (after full bloom), minimally trimmed and dipped in less than or equal to 5% sodium metabisulphite solution for less than or equal to 5 min. In the West Indies and many African countries the water nuts are sold from pickup trucks at the roadside, where the vendor will slice the top off so the water can be drunk. They will then slice the nut into two and cut a spoon from the husk so that the jelly inside can be scooped up and eaten.

Postharvest physiology

Ethylene production is close to zero for mature husked coconuts and there are no reports of their sensitivity to ethylene. Their respiration rate was $45\text{--}55\text{ mg CO}_2\text{ kg}^{-1}\text{ h}^{-1}$ ($26\text{--}32\text{ }\mu\text{l CO}_2\text{ kg}^{-1}\text{ h}^{-1}$) at 25°C . Their freezing point is -3°C .

Storage

The white copra is commonly preserved by extraction, shredding and drying. If it is not dried sufficiently fungi, which can produce toxins, can infect it. The most common of these is aflatoxin, which is mainly produced by *Aspergillus flavours* and *A. parasitic*. These fungi infect dozens of food products and coconuts. Refrigerated storage recommendations for the intact nut are as follows:

- $0\text{--}1.7^\circ\text{C}$ and 85–90% r.h. for 1–2 months (Wardlaw 1937);
- $0\text{--}1.5^\circ\text{C}$ and 75–85% r.h. for up to 60 days or $13\text{--}16^\circ\text{C}$ and 80–85% r.h. for up to 2 weeks for mature, dehusked coconuts (Muliya and Marar 1963);
- $0\text{--}1.5^\circ\text{C}$ and 80–85% r.h. for 1–2 months (Hardenburg *et al.* 1990);
- 0°C and 85–90% r.h. for 30–60 days (SeaLand 1991);
- $3\text{--}6^\circ\text{C}$ with 90–95% r.h. for young coconuts (Tongdee *et al.* 1992).

Waternuts may be stored in PE film bags or coated with wax to reduce desiccation (Lutz and Hardenburg 1968).

Colic root

Dioscoreaceae

Dioscorea villosa L., *D. villosa* L. var. *glabrifolia* (Bartlett) Fernald. Coursey (1968) reported that it was native to the eastern part of north America where it was formally used for the treatment of colic. Sturtevant (1892) wrote 'N. F. IV. An indigenous, perennial, twining plant, with long, knotty, matted, contorted, ligneous root stocks. It grows from Ontario to Wisconsin and south to Florida and Texas. The rhizome is used by the eclectics, who consider the drugs efficacious in *bilious colic*, and by the southern

negroes in *rheumatism*.' The rhizome is described by the N.F. as 'knotted and woody, elongated, from 6 to 12 mm in thickness, often compressed, bent and branched, bearing scattered nodular projections at the sides, slender, tough roots underneath and stem scars on their upper surface; externally pale brown, surface more or less scaly from the partly detached, thin outer layer; fracture short but tough, the fractured surface whitish or pale-brown, with numerous small, scattered, yellowish wood bundles. Odourless; taste starchy, insipid, afterwards acrid. *Dioscorea* yields not more than 7% of ash.' N.F. 'W.C. Kalteyer found abundant saponin in the roots. (A.J.P. 1888; see also M.R. 1913, 311.) A substance, improperly called dioscorein, obtained by precipitating the tincture with water, is used in the dose from one to four grains (0.0065–0.26 Gm.). Dose, one-half to one drachm (1.9–3.75 ml), which may be given in the form of either a decoction or a fluid extract.'

Corn salad

Valerianaceae

Valerianella locusta (L.) Latterrade em. Betcke synonymous with *V. olitoria* L. Other common names include field salad, lamb's lettuce and mâche. The name corn salad refers to the fact that it often grows as a weed in wheat fields. It is native to the Mediterranean basin but it is grown throughout Europe and America where it is appreciated for its good taste and dietary characteristics. It is an herbaceous plant either an annual or a biennial plant according to sowing time and can be cultivated during the whole year with repeated sowings (Nicola *et al.* 2004).

The leaves are harvested when still young and fresh and they may be packed as bunches of leaves or plants cut-off at the base of the stem (Péron and Rees 1998). Nicola *et al.* (2004) reported that during storage of plants, grown in soil less conditions, at 4 °C for 8 days, their quality index fell from 96.1 to 11.7% and they lost some 17% in fresh weight. Quality index was defined as 100% for the highest marketable value. De Leiris (1987) reported that they retained acceptable quality in storage at less than 4 °C for 28 days in sealed plastic bags with reduced O₂ and elevated CO₂.

Courgettes

Cucurbitaceae

Cucurbita pepo L. are the vegetable marrows or squash and *C. pepo* var. *melopepo* Alef. refers to those that are usually harvested immature. They are called courgettes and other common names include baby marrow, bush squash, summer squash and zucchini. The fruit is a pepo and at the normal stage of harvest it contains numerous soft undeveloped seeds that are white. The cultivars with dark green skin are usually preferred, although there are exceptions e.g. in the Sudan the local market is mainly for the pale green to yellowish skinned types.

Harvesting and handling

Harvesting is when they reach a size that is required by the market. This is generally about 15 cm long, but some markets prefer them up to 30 cm long and there is a market for 'baby courgettes' which are 7 or 8 cm long. They are very easily bruised and great care must be taken during harvesting and handling. Forced-air cooling with high humidity was the most suitable, air cooling in a conventional cold store was also suitable and vacuum cooling and hydrocooling were generally unsuitable (MAFF n.d.).

Postharvest physiology

Summer squash produce 0.1–1.0 µl kg⁻¹ h⁻¹ ethylene at 20 °C but exposure of cultivars with green skins can increase yellowing (Ryall and Lipton 1979). Their respiration rates are given in Table 56.

Storage

In ambient conditions in the Sudan some 50% were considered inedible 2 days after harvest. At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 3–5 days. Chilling injury occurred after 10–14 days at 0 °C (Lutz and Hardenburg 1968) or when exposed to temperatures less than 5 °C (Ryall and Lipton 1979) but great variation in chilling tolerance was reported by Suslow and Cantwell (1998a). Symptoms include the skin turning yellow when removed to higher

Table 56 Respiration rate of courgettes at different temperatures (source: adapted from Hardenburg *et al.* 1986)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	24–26
5	27–37
10	65–68
15	139–167
20	153–175

temperatures and developing surface. Refrigerated storage recommendations were as follows:

- 2.2–10 °C (Wardlaw 1937);
- 5.6 °C for several weeks (Wardlaw 1937);
- 0 °C and 85–90% r.h. for less than 2 weeks (Phillips and Armstrong 1967);
- 0–4.4 °C and 90% r.h. for 4–5 days (Anonymous 1968, Lutz and Hardenburg 1968);
- 7.2–10 °C and 90% r.h. for less than 2 weeks (Lutz and Hardenburg 1968);
- 10 °C and 95% r.h. for 7 days (Tindall 1983);
- 10 °C and 90% r.h. for 2–3 weeks (Mercantilia 1989);
- 10 °C and 90–95% r.h. for 7–14 days soft skinned summer types (SeaLand 1991);
- 7.2 °C and 90–95% r.h. for 14–21 days (SeaLand 1991);
- 8–10 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1991).

Controlled atmosphere storage

SeaLand (1991) recommended 5–10% CO₂ + 3–5% O₂ which had a slight to no effect and Hardenburg *et al.* (1990) reported that storage at 5 °C in low O₂ was of little or no value. However, controlled atmosphere storage has been shown to reduce respiration rate, ethylene production and chilling injury. The best quality maintenance of the cultivar Astra was in storage at 6 °C in air and 3 °C in 5% CO₂ + 3% O₂ or 3% CO₂ + 3% O₂ but storage at 3 °C caused chilling injury of young fruits (10–16 cm long) after 2 weeks (Gajewski and Roson 2001). Subsequently Gajewski (2003) reported that best results were obtained if Astra was kept at 6 °C in either 5% CO₂ + 3% O₂ or 3% CO₂ + 3% O₂. Storage in 1% O₂ reduced chilling injury symptoms at 2.5 °C compared to storage in air. Symptoms occurred after 9 days of storage compared

with 3 days of storage in air (Chien and Kramer 1989, Wang and Ji 1989). Mencarelli *et al.* (1983) had also shown that storage at 2.5 °C resulted in chilling injury, but the effect could be ameliorated by holding them in 1, 2 or 4% O₂ instead of 8 or 21% O₂. Wang and Kramer (1989) also found that storage in 1% O₂ reduced chilling injury symptoms at 2.5 °C compared to storage in air. Mencarelli (1987a) found that storage at about 5 °C normally caused chilling injury but CO₂ concentrations around 5% delayed its development in the cultivar Romanesco during 19 days of storage of three harvest maturities (16, 20 and 22 cm long fruits).

Diseases

Common postharvest diseases include alternaria rot, bacterial soft rot, cottony leak, fusarium rot, phythophthora rot and rhizopus rot.

Crape ginger

Costaceae

Costus speciosus Koen. (Keukand) or *Cheilocostus speciosus*. Other common names include costus, ginger, isabsab, keu, kemuk, keumul, keukand, thebu, pakarmula, pushkarmula, jom lakhuti and kostam. It is native of South East Asia, especially some Indonesian islands and many Pacific islands although Specht and Stevenson (2000) reported that it was native to the Malaysian Peninsula. Schoff (1912) claimed Indian origin since the word *Costus* is derived from the Sanskrit term *kustha*. It has since been introduced and naturalized in some tropical areas and has become an invasive species in some countries including the Cook Islands, Fiji and Hawai'i. It is widely distributed in India in the tropical or sub-tropical areas from sea level to the Himalayas in moist tropical evergreen forests up to an altitude of 1200 m. It is common along roadsides, streams and in wasteland (Srivastava *et al.* 2011). It was used by the Romans as a culinary spice and as a perfume and the price was stated by Pliny to have been 5 Denarii per pound (Schoff 1912). It is cultivated in India for its medicinal uses and elsewhere as an ornamental. Various medicinal properties are attributed to it particularly in the treatment of asthma, fungal diseases, rheumatism, diabetes and hepatoprotective disorders (Anonymous 2007).

It is a perennial, erect, succulent herb, up to 2.7 m in height arising from a horizontal rhizome. Rhizomes are covered with sheaths in the lower parts and leafy in the higher parts with leaves that are elliptic to oblong in shape with stem-clasping sheaths. Flowers are large and white and are produced in cone-like terminal spikes. The fruits are globose red capsules about 2 cm in diameter containing black seeds. The rhizome is yellowish brown, cylindrical, up to 30 cm in length and 3–5 cm in diameter with the upper surface marked with circular nodal scars with remnants of leaf bases. The lower and lateral surfaces have small circular scars of roots or a few wiry rootlets (Srivastava *et al.* 2011). Qiao *et al.* (2002) found diosgenin, prosapogenin B of dioscin, diosgenone, cycloartanol and octacosanoic acid in the rhizomes of *C. speciosus*. They also tested *Costus tonkinensis* and found tetra-cosanoic acid, succinic acid, β -sitosterol and daucosterin from their rhizomes. Srivastava *et al.* 2011 reviewed the constituents of the roots and listed 19 chemicals.

Cress

Cruciferae

Lepidium sativum L. it is also called garden cress. *L. sativum* has been divided into three varieties: *crispum* (the most xeromorphic), *latifolium* (the most mesomorphic) and *vulgare* (intermediate between the other two). It is native to south west Asia, perhaps Iran, and its cultivation spread many centuries ago to Western Europe. Xenophon (400 BCE) mentions that the Persians used to eat cress and it was also familiar to the ancient Egyptians, the Greeks and Romans. In the 1st century book *Los doce libros de Agricultura*, by Columela it states ‘... immediately after the calends of January, garden cress is sown out... when you have transplanted it before the calends of March, you will be able to harvest it like chives, but less often... it must not be cut after the calends of November because it dies from frosts, but can resist for two years if it is hoed and manured carefully... there are also many sites where it lives for up to ten years’ (Book XI). This may indicate that he was referring to the perennial species *L. latifolium* (Nuez and Hernández Bermejo 1994). It is an annual, erect herbaceous plant, growing up to 50 cm in height. The basal leaves have long petioles

and are lyrate-pinnatipartite; the caulinar leaves are lacinate-pinnate while the upper leaves are entire (Nuez and Hernández Bermejo 1994).

Kasim and Kasim (2012) treated fresh cut cress with UV-C for 30 min and found that it prevented yellowing, reduced chlorophyll loss during storage at 5 °C and 95% r.h. for 7 days, but increased electrolyte leakage due to tissue damage. They recommended that lower doses of UV-C should be used. Fontana and Nicola (2008) found that the optimum storage temperature to maintain freshness was 4 °C, while PP films limited loss in weight to less than 2%. They also indicated that low nitrate content was important for the fresh-cut supply chain with an acceptable nitrate content in the leaves of less than 2500 mg kg⁻¹ fresh weight.

Cucumber

Cucurbitaceae

Cucumis sativus L. Purselove (1972) reported that it originated in northern India and is related to *C. hardwickii* Royle that occurs wild or it might be a form of *C. sativus* that have escaped cultivation. *C. sativus* has now spread throughout the world. It is a monoecious annual climbing or trailing herb with stiff bristly hairs. Male flowers predominate in axillary clusters and female flowers have three united inferior carpels. The fruit is an indehiscent pendulous berry called a pepo. It varies in shape from long and cylindrical to almost globular and usually has a dark green skin, but there are yellow cultivars, with whitish green flesh that contains many flat white seeds in the central area. Cucumbers may also be seedless. Cucumber will freeze at about –0.9 to –0.8 °C (Wright 1942) or –0.83 to –0.72 °C (Weichmann 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 57. Total world production for cucumbers and gherkins in 2010 was estimated by FAO (2012) as 62,430,796 tonnes.

Harvesting and handling

This is when they reach a marketable size, but before they begin to turn yellow and before the seeds develop, as this is associated with a bitter flavour. Forced-air cooling with high humidity was the most acceptable method, air cooling in a conventional cold

Table 57 The composition of cucumber fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	95.23 g	Thiamine	0.027 mg
Energy	15 kcal	Riboflavin	0.033 mg
Protein	0.65 g	Niacin	0.098 mg
Total lipid (fat)	0.11 g	Vitamin B-6	0.040 mg
Carbohydrate, by difference	3.63 g	Folate	7 µg_DFE
Total dietary fibre	0.5 g	Vitamin B-12	0.00 µg
Sugars, total	1.67 g	Vitamin A	5 µg_RAE
Calcium	16 mg	Vitamin A	105 IU
Iron	0.28 mg	Vitamin E (α-tocopherol)	0.03 mg
Magnesium	13 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	24 mg	Vitamin D	0 IU
Potassium	147 mg	Vitamin K (phyloquinone)	16.4 µg
Sodium	2 mg	Fatty acids, total saturated	0.037 g
Zinc	0.20 mg	Fatty acids, total monounsaturated	0.005 g
Total ascorbic acid	2.8 mg	Fatty acids, total polyunsaturated	0.032 g

store was suitable and hydrocooling was less suitable and vacuum cooling was generally unsuitable (MAFF n.d.).

Prestorage treatment

Chitosan has been successfully used as a postharvest coating of cucumbers to reduce water loss and maintain their quality (El Ghaouth *et al.* 1991). Wax was sometimes applied to enhance their appearance (Lutz and Hardenburg 1968). Lima *et al.* (2005) found that exposure of different cultivars to 1.0 µl L⁻¹ of 1-MCP resulted in significant retention of firmness and surface colour in the cultivar Sweet Marketmore but it had minimal effects on the cultivar Thunder. They found that those exposed to 10 µl L⁻¹ ethylene at 15 °C showed rapid and acute cellular breakdown within 4 days, but this effect was reduced, but not eliminated, by the 1-MCP treatment. Nilsson (2005) also found some benefit in delaying degreening with 1-MCP, especially when they were exposed to ethylene. However it was concluded that they probably showed little benefit from 1-MCP unless exogenous ethylene was present. Skog and Chu (2001) found that ozone at 0.04 µl L⁻¹ introduced into store rooms extended the storage life of cucumbers.

Postharvest physiology

It is classified as non-climacteric. Exposing them to ethylene can result in the rapid breakdown of chlorophyll (Poenicke *et al.* 1977). Storage in 30% CO₂ accelerated ethylene evolution possibly due to an early injury response (Pal and Buescher 1993). Exposure to 10 µl L⁻¹ ethylene increased respiration rate in fruit of all stages of development; however, ethylene production was detectable only in decaying fruit (Hurr *et al.* 2009). Inaba *et al.* (1989) found that there was increased respiration rate in response to ethylene at 100 µl L⁻¹ for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures.

Harvesting

Hurr *et al.* (2009) reported that greenhouse grown mini-cucumbers of the cultivar Manar were harvested at four stages of development: 4–8 (immature), 10–14 (mature), 16–20 (breaker) and 35–40 (yellow) days after anthesis and stored in air or 10 µl L⁻¹ ethylene for 12 days at 15 °C. Ethylene-treated immature fruit exhibited mesocarp water soaking and epidermal sloughing, slight degreening and declines in mesocarp pH and firmness compared with those stored in air after 6 days of storage. Mature fruit behaved similarly to immature fruit but exhibited a lower incidence of water soaking and greater fruit degreening. In sharp contrast, breaker and yellow fruit rapidly degreened and became orange due to chlorophyll degradation and β-carotene accumulation; they softened and produced 'fruity' aromatic compounds after 9 days of ethylene exposure.

Storage

Ethanol accumulation was significantly increased by storage for 42 h at 18 °C compared to those stored at 8 °C, but storage at 28 °C did not cause any further increase than storage at 18 °C (Yanez Lopez *et al.* 1998). Chilling injury can occur at temperatures below 10 °C (Wardlaw 1937, Tindall 1983), 4.4–6.1 (Pantastico 1975), 7.2 °C for 2 days which had a slight effect but became severe after 6 days (Lutz and Hardenburg 1968). Chilling injury causes dark coloured watery blemishes (Wardlaw 1937), pitting, tissue collapse (Lutz and Hardenburg 1968), fungal infection and decay especially when they have been moved to higher temperatures (Anonymous 1968,

Lutz and Hardenburg 1968, Pantastico 1975). Jufang Dong *et al.* (2012) found that during storage at 4 °C fruit that had been treated with 0.5 g L⁻¹ yeast saccharide had significantly less chilling injury compared with those not treated. Refrigerated storage recommendations were as follows:

- 0 °C or 4.4 °C (Platenius *et al.* 1934);
- 10–15.6 °C (Wardlaw 1937);
- 0 °C and 85% r.h. (Wardlaw 1937);
- 1.7 °C and 85% r.h. for 3–4 weeks (Wardlaw 1937);
- 7.2 °C and high humidity (Wardlaw 1937);
- 10 °C for 20–25 days (Wardlaw 1937);
- 7–10 °C and 90–95% r.h. for up to 2 weeks (Anonymous 1967);
- 7.2 and 95% r.h. for 10–14 days (Phillips and Armstrong 1967);
- 7.2–10 °C and 90–95% r.h. for 10–14 days (Lutz and Hardenburg 1968, Anonymous 1968);
- 10–11.7 °C and 92% r.h. for 2 weeks with 7.2% weight loss (Pantastico 1975);
- 13 °C and 95% r.h. for approximately 14 days with a weight loss of 7–10% (Tindall 1983);
- 13 °C and 90–95% r.h. for 10 days (Mercantilia 1989);
- 10 °C and 90–95% r.h. for 10–14 days (SeaLand 1991);
- 8–11 °C and 90–95% r.h. for 1–2 weeks (Snowdon 1991).

Controlled atmosphere storage

Low-temperature storage was shown to result in a lower respiration rate with some slight additional effects of reduced levels of O₂ (Table 58). Over a 24-h period at 10 or 20 °C the respiration rate of the cultivar Tyria decreased as the O₂ concentration decreased down to 0.5%, but at 0% O₂, the respiration rate increased because of fermentation (Praeger and Weichmann 2001). Storage in 5% O₂ was shown to retard yellowing (Lutz and Hardenburg 1968).

Table 58 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of cucumbers (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	6	8	13	14	15
In 3% O ₂	5		8		10

Short time exposure to 10 or 20% CO₂ reduced the respiration rate of pickling cucumbers (Pal and Buescher 1993). CA storage recommendations were as follows:

- 14 °C with 5% CO₂ + 5% O₂ (Stoll 1972).
- 8.3 °C with 3–5% O₂ gave a slight extension in storage life (Pantastico 1975).
- 5% CO₂ with 5% O₂ extended their storage life (Pantastico 1975, Ryall and Lipton 1979).
- 8–12 °C with 0% CO₂ and 3–5% O₂ had a fair effect but was of no commercial use (Kader 1985, 1992).
- 12.5 °C in 5% O₂ + 5% CO₂ (Schales 1985).
- A maximum of 10% CO₂ and a minimum of 3% O₂ (Fellows 1988).
- 12 °C with 0% CO₂ and 1–4% O₂ for the fresh market, and 4 °C with 3–5% CO₂ and 3–5% for pickling both of which had only a slight effect (Saltveit 1989).
- 10 °C and 90–95% r.h. with 5–7% CO₂ and 3–5% O₂ (SeaLand 1991).

Controlled atmosphere storage can affect susceptibility to chilling injury associated with solubilization of cell wall polysaccharides (Mercer and Smittle 1992). Eaks (1956) showed that high CO₂ in the storage atmosphere could have detrimental effects in that it appeared to increase their susceptibility to chilling injury when they were stored at lower temperatures. Mercer and Smittle (1992) stored the cultivar Gemini II in 0, 5 or 10% CO₂ + 5 or 20% O₂ at 5 or 6 °C for 2, 4 or 6 days or at 5 °C for 5 days or at 3 °C for 10 days and then 2–4 days at 25 °C. High CO₂ and low O₂ delayed the onset of chilling injury symptoms but did not prevent their development and symptoms increased with longer exposure.

Pre-treatment with O₂ has been shown to be beneficial. In storage at 5 °C pre-treatment with 100% O₂ for 48 h lowered the respiration rate compared to storage in either 5% O₂ or air. It also delayed the appearance of fungal decay by 2 days, delayed the onset of and reduced the severity of chilling injury, halved weight loss and delayed the appearance of shrivelling by 4 days compared to the control (Srijaong *et al.* 2005). Reyes (1989) showed that the virulence of mucor rot (*Mucor mucedo*) and grey mould (*Botrytis cinerea*) were suppressed in 7.5% CO₂ + 1.5% O₂.

Modified atmosphere packaging

In Europe fruit are commonly marketed in a shrink-wrapped plastic sleeve to help retain their texture and colour, which provides a modified atmosphere. Lee and Lee (1996) used 27 μm thick LDPE film for the preservation of a mixture of carrot, cucumber, garlic and green peppers. The equilibrium atmosphere at 10 °C inside the bags was 5.5–5.7% CO_2 and 2.0–2.1% O_2 . Beit-Alpha cucumbers responded favourably to modified atmosphere packaging with up to 8–9% CO_2 , showing reduced physiological disorders and decay, but CO_2 levels above 10% were injurious. The combination of optimal atmosphere composition and humidity inhibited the cucumber toughening and preserved their tender texture and turgidity (Rodov *et al.* 2003). Cucumbers stored in 100% O_2 in plastic bags retained their fresh appearance but developed off-flavours and at 5 °C the level of O_2 in the bags had fallen to 50% and CO_2 had risen to 20% after 8 days (Srilaong *et al.* 2005). Mineral powders are incorporated into some films particularly in Japan where it was claimed that among other thing these films can remove or absorb ethylene, excess CO_2 and water and can be used for cucumber (Industrial Material Research 1989, quoted by Abe 1990).

Hypobaric storage

Hypobaric storage at 0.1 atm. (76 mm Hg) extended the storage life to 7 weeks, compared with 3–4 weeks in cold storage (Bangerth 1974) and reduced respiration rate by 67–75%. Burg (2004) reported that storage at 7.2 °C resulted in chilling injury and reducing the pressure to 100, 120 or 160 mm Hg reduced chilling injury. However, in 80 mm Hg there were no symptoms after 7 weeks but chilling injury occurred within 1 or 2 days when they were removed to ambient conditions.

Daikon

Cruciferae

Raphanus sativus var. *acanthiformis*. Other common names include radish, white radish, mooli, oriental radish, lobak, lobok, Japanese radish, Korean radish and Chinese radish. The edible portion is the



Figure 31 Mooli on sale in Britain in 2013.



Figure 32 Lobok on sale in a Californian supermarket in 2008. See colour plate section.

cylindrical white or brown roots which are long and slender, up to 40 or 50 cm long, and usually weigh up to 2 kg (Figures 31, 32), but can be as much as 20 kg in some Japanese cultivars. They can be eaten raw but are most often cooked. They have a strong fiery taste because of the presence of mustard oils (Mercantilia 1989). The flavour is generally rather mild compared to salad radishes. The most common variety in Japan is the F_1 hybrid Aokubi-Daikon. There are three distinct shapes: spherical, oblong and cylindrical. Roots are eaten raw or cooked and in some countries, the leaves are also eaten as a vegetable (Morgan and Midmore 2003). The chemical content was given by USDA Nutrient Database (2012a) in Table 59.

Table 59 The composition of oriental radishes *Raphanus sativus* (Longipinnatus Group) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	94.62 g	Total ascorbic acid	22.0 mg
Energy	18 kcal	Thiamine	0.020 mg
Energy	76 kJ	Riboflavin	0.020 mg
Protein	0.60 g	Niacin	0.200 mg
Total lipid (fat)	0.10 g	Pantothenic acid	0.138 mg
Ash	0.58 g	Vitamin B-6	0.046 mg
Carbohydrate, by difference	4.10 g	Folate, total	28 µg
Total dietary fibre	1.6 g	Folic acid	0 µg
Sugars, total	2.50 g	Folate, food	28 µg
Calcium	27 mg	Folate	28 µg_DFE
Iron	0.40 mg	Choline, total	7.3 mg
Magnesium	16 mg	Betaine	0.1 mg
Phosphorus	23 mg	Vitamin B-12	0.00 µg
Potassium	227 mg	Vitamin B-12, added	0.00 µg
Sodium	21 mg	Vitamin A	0 µg_RAE
Zinc	0.15 mg	Vitamin K (phylloquinone)	0.3 µg
Copper, Cu	0.115 mg	Fatty acids, total saturated	0.030 g
Manganese, Mn	0.038 mg	Fatty acids, total monounsaturated	0.017 g
Selenium, Se	0.7 µg	Fatty acids, total polyunsaturated	0.045 g

Harvesting and handling

They should be harvested during the coolest part of day and kept cool and moist until placed in storage (Nguyen 1992). They are harvested when still crisp and with a pungent mustard taste and are considered best when the flesh is snow white. Days to harvest ranged from 61 to 112 days depending on the time of the year (Morgan and Midmore 2003). In Australia the preferred market weight was 1 kg that was reached in 60 days in the spring–summer period and 82–85 days in the autumn–winter period (Harris *et al.* 2000). They should be cooled quickly to 4 °C or below to maintain their crispness. Hydrocooling was reported to be an effective method of cooling radishes (Lutz and Hardenburg 1968). Rapid cooling with forced draught air was recommended by Nguyen (1992). Holmes and Kemble (2009) recommended room cooling for oriental radishes grown in the southern United States. Black spot was reduced by washing radishes in chlorinated water (Lutz and Hardenburg 1968).

Storage

The limiting factor to storage is usually when they sprout. Their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be about 1 week (Mercantilia 1989). Refrigerated storage recommendations are as follows:

- 0 °C and 90–95% r.h. for 2–4 months (Kay 1987);
- 0 °C and 90–95% r.h. for 4 months (Mercantilia 1989);
- 4 °C for 2 months (Mercantilia 1989);
- 8 °C for 1 month (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 60–120 days (SeaLand 1991).

Kay (1987) recommended 0 °C and 90–95% r.h. for 2–4 months. At higher temperatures storage may be terminated by sprouting although the naturally occurring campothecin was said to inhibit sprouting allowing successful storage at 10–20 °C (Kay 1987). Harris *et al.* (2000) found that Tomas was the best cultivar overall, and market quality was maintained during a simulated export period of 4 weeks, provided it was harvested at the preferred market weight of 1 kg. All leaf material should be trimmed from the before storage. Postharvest life was limited mainly by the physiological disorder pithiness (Harris *et al.* 2000). At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 1 week. Refrigerated storage recommendations are as follows:

- 0 °C and 90–95% r.h. for 4 months (Mercantilia 1989);
- 4 °C for 2 months (Mercantilia 1989);
- 8 °C for 1 month (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 120 days (SeaLand 1991);
- 0 °C and 95–100% r.h. (Nguyen 1992);
- 0 °C and 95–100% r.h. for 3–4 months (Suslow 2000);
- 0 °C and 95–100% r.h. for 2–4 months for oriental radishes grown in the southern United States (Holmes and Kemble 2009).

Modified atmosphere packaging

With *R. sativus* var. *longipinnatus* O₂ and CO₂ concentrations inside different microperforated film bags varied between 0.2 and 15% O₂ and 5 and 16% CO₂ at 15 °C after 6 days of storage depending on the degree

of microperforation. Films that gave an equilibrium concentration of 9–13% O₂ + 8–11% CO₂ were suitable to maintain most of the qualitative parameters and avoiding the development of off-flavours during 6 days of storage (Saito and Rai 2005). Postharvest trials at 1 and 1.7 °C suggest that storage in sealed LDPE bags maintained quality, even up to 36 days of storage (Morgan and Midmore 2003). It was also reported that during storage in HDPE bags there was relatively consistent CO₂ levels of 1.24–2.87%. Storage in the LDPE bags resulted in higher levels of CO₂ but much lower levels of O₂ compared with the HDPE. Storage in the LifeSpan®L144 bags resulted in relatively consistent CO₂ levels of 2.94–5.84% while the O₂ concentrations in the LifeSpan®L144 bags ranged from 7.19 to 16.67% with a sharp decrease in O₂ after 33 days of storage (McVeigh *et al.* 2001). No visible CO₂ injuries were reported. After 36 days of storage at about 1 °C, those sealed in LDPE bag retained their quality. Therefore, a modified atmosphere of 6.5% CO₂ and 2.5% O₂ appeared to maintain Daikon quality suitable for export markets. In the second trial they reported that where Daikon was stored for 28 days at 1.7 °C, cartons without liners had a weight loss of 10.7–11.2%. Regardless of the wide range of O₂ levels in the LifeSpan®L144 bag, the quality of roots was retained during the storage period of 28 days. Roots in the HDPE bags had the best quality ratings.

Physiological disorder

The physiological disorder pithiness is characterized by the formation of air spaces in the root that will eventually leave it spongy, dry and hollow. It developed both in the field and in storage (Harris *et al.* 2000). The development of pithiness was related to cultivar, but not to senescence, since it developed in the field in Long White from an early stage of growth.

Doyala yam

Dioscoreaceae

Dioscorea tomentosa J. Koenig ex Sprengel. It is also called taragai kanda, ooyala yam and kyway pin. Sturtevant (1892) wrote 'East Indies. This is the Doyala yam of India'. Leaves are heart shaped and glossy. Tubers are up to 30 cm long and 5–7 cm in diameter

and branch laterally, which makes them resemble the fingers of a hand. They have a white and hairy skin with white flesh. The tubers are used as a contraceptive by some Indian tribes.

Mohan and Kalidass (2010) gave the following composition: 93.65% moisture, 8.31 ± 0.12 crude protein, 6.84 ± 0.04 crude lipid, 4.38 ± 0.18 crude fibre, 6.53 ± 0.03 ash, 73.93 nitrogen-free extractives, $1631.44 \text{ g } 100 \text{ g}^{-1}$ calorific value (kJ 100 g^{-1} dry matter), 15.29 ± 0.09 starch, 14.12 ± 0.02 niacin and 24.92 ± 0.21 ascorbic acid g 100 g^{-1} . They also gave *in vitro* protein digestibility as 4.98% and *in vitro* starch digestibility as 56.84%. Shajeela *et al.* (2011) gave the following: starch $51.36 \pm 0.27 \text{ g } 100 \text{ g}^{-1}$, niacin $74.12 \pm 0.21 \text{ mg } 100 \text{ g}^{-1}$ and ascorbic acid $65.20 \pm 0.21 \text{ mg } 100 \text{ g}^{-1}$. Anti-nutritional factors identified by Mohan and Kalidass (2010) were as follows: total free phenolics $0.23 \pm 0.10 \text{ g } 100 \text{ g}^{-1}$, tannins $0.07 \pm 0.48 \text{ g } 100 \text{ g}^{-1}$, hydrogen cyanide $0.05 \pm 0.01 \text{ mg } 100 \text{ g}^{-1}$, total oxalate $0.03 \pm 0.01 \text{ g } 100 \text{ g}^{-1}$, amylase inhibitor $1.54 \text{ AIU mg soluble starch}^{-1}$ and trypsin inhibitor $0.87 \text{ TIU mg protein}^{-1}$. Shajeela *et al.* (2011) gave the following analysis for anti-nutritional factors: total free phenolics $0.41 \pm 0.01 \text{ g } 100 \text{ g}^{-1}$, tannins $0.06 \pm 0.01 \text{ g } 100 \text{ g}^{-1}$, hydrogen cyanide $0.34 \pm 0.03 \text{ mg } 100 \text{ g}^{-1}$, total oxalate $0.31 \pm 0.11 \text{ g } 100 \text{ g}^{-1}$, amylase inhibitor 4.64 AIU mg^{-1} soluble starch and trypsin inhibitor $1.41 \pm 0.11 \text{ TIU mg}^{-1}$ protein.

Drumstick tree

Moringaceae

Moringa oleifera Lam. synonymous with *M. pterygosperma*. Other common names include moringa and horseradish tree. It is native to India and is cultivated there as well as Bangladesh, Thailand, the Philippines, Africa, Cambodia, Nepal, Indonesia, Malaysia, Mexico, Central and South America and Sri Lanka. They were being grown as fences in the Central Lowlands of Eritrea but there was no apparent use of their pods or leaves.

The immature tender seed pods are consumed in South Asia and are particularly high in vitamin C. The leaves are the most nutritious part of the plant, being a significant source of vitamin B6, vitamin C, provitamin A as β -carotene. They are used in soup and are also cooked and used like spinach. The seeds

Table 60 The composition of horseradish tree leaves (*Moringa oleifera*) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	78.66 g	Zinc	0.60 mg
Energy	64 kcal	Vitamin C, total ascorbic acid	51.7 mg
Protein	9.40 g	Thiamine	0.257 mg
Total lipid (fat)	1.40 g	Riboflavin	0.660 mg
Carbohydrate, by difference	8.28 g	Niacin	2.220 mg
Fibre, total dietary	2.0 g	Vitamin B-6	1.200 mg
Calcium	185 mg	Folate, DFE	40 µg
Iron	4.00 mg	Vitamin B-12	0.00 µg
Magnesium	147 mg	Vitamin A, RAE	378 µg
Phosphorus	112 mg	Vitamin A, IU	7564 IU
Potassium	337 mg	Vitamin D (D2 + D3)	0.0 µg
Sodium	9 mg	Vitamin D	0 IU

can be removed from mature pods and eaten like peas or roasted like nuts and contain high levels of vitamin C and moderate amounts of B vitamins and dietary minerals. They also contain some 38–40% edible oil. Various parts of the tree are also use in traditional medicine. The roots have a spicy flavour and may be shredded and used as a condiment in the same way as horseradish (Olson and Carlquist 2001).

It is a slender tree up to about 10 m high with drooping branches. They can be pruned annually to 1–2 m to encourage growth and to facilitate easy harvesting of the leaves and the long, slender, triangular seed pods (Olson and Carlquist 2001). The chemical content was given by USDA Nutrient Database (2012a) in Table 60 for the leaves and Table 61 for the pods. Except for ascorbic acid the pods generally have a lower vitamin content. Trees that have been propagated by cutting begin producing pods some 6–8 months after planting with regular bearing in the second year, which continues for several years. Trees propagated by seed take longer before the first pods are produced.

East Indian arrowroot

Taccaceae

Tacca leontopetaloides (L.) Kuntze synonymous with *T. pinnatifida* Forst. and *T. involucrata* Schum. and Thonn. Other common names include Fiji arrowroot, Indian arrowroot, Polynesian arrowroot, tacca, Tahiti arrowroot and Williams arrowroot. It probably

Table 61 The composition of horseradish tree pods (*Moringa oleifera*) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	88.20 g	Vitamin C, total ascorbic acid	141.0 mg
Energy	37 kcal	Thiamine	0.053 mg
Protein	2.10 g	Riboflavin	0.074 mg
Total lipid (fat)	0.20 g	Niacin	0.620 mg
Carbohydrate, by difference	8.53 g	Vitamin B-6	0.120 mg
Fibre, total dietary	3.2 g	Folate, DFE	44 µg
Calcium	30 mg	Vitamin B-12	0.00 µg
Iron	0.36 mg	Vitamin A, RAE	4 µg
Magnesium	45 mg	Vitamin A, IU	74 IU
Phosphorus	50 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	461 mg	Vitamin D	0 IU
Sodium	42 mg	Fatty acids, total saturated	0.033 g
Zinc	0.45 mg	Fatty acids, total monounsaturated	0.102 g
		Fatty acids, total polyunsaturated	0.003 g

originated in South East Asia and was introduced to the Pacific islands very early where, at one time, it was a staple food (Purseglove 1972). It was subsequently introduced throughout tropical Asia, tropical Africa and tropical Australia. Its importance has declined and it is not cultivated in Africa and only sporadically elsewhere, although it has persisted throughout its range of early distribution in a wild state. There are some 30 species of *Tacca*, which are perennial herbs (Purseglove 1972). Most plants produce many starchy tubers, similar in appearance to potatoes (*Solanum tuberosum*), usually 10–15 cm in diameter, but they can reach 30 cm on rich soils. They normally weigh from 70 to 340 g but can reach 1 kg. The tubers have eyes, a pale-yellow skin and dull-whitish flesh and are usually bitter and almost inedible when raw. An analysis of Tahitian tubers has been given by Kay (1987) as 60.59% water, 30.6% starch, 6.3% fibre and 2.5% skin. She also gives an analysis of African tubers on a dry weight basis as 89.4% carbohydrate, 5.1% protein, 2.1% cellulose, 8.8% fibre, 3.2% ash, 0.27% calcium, 0.2% phosphorus and 0.2% ether extract. The principal amino acids present were arginine, glutamic and aspartic acids, leucine, Iysine and valine.

They are harvested when the tops die down (Purseglove 1972) and are dug up by hand. In Hawai'i, the leaves appear in the early spring and the crop

is mature by the end of the summer, approximately 8 months from planting, though under some conditions the crop can take up to 10½ months to reach maturity (Kay 1987). They are sometimes stored in pits and sprouting appears to be the limiting factor in storage. The tubers are very bitter so before eating they are peeled and grated, washed in several changes of water and then strained through a cloth. The resultant product being a kind of arrowroot. In the earlier days this was much used and highly recommended for dysentery and diarrhoea in the same way as West Indian arrowroot (*Maranta arundinacea*) has been used.

Elephant foot yam

Araceae

Amorphophallus paeoniifolius (Dennst.) Nicolson, synonymous with *A. campanulatus* Decne. According to some authorities it exists in two forms, the wild one *A. campanulatus* var. *sylvestris*, recognizable by its rough petioles, while the cultivated form *A. campanulatus* var. *hortensis* has much smoother petioles. In Indonesia two closely related species *A. oncophyllus* Prain and *A. variabilis* Bl. occur and are utilized. In addition, *A. konjac* C. Koch (synonymous with *A. rivieri* Durien var. *konjac* (C. Koch) Engler) is cultivated and utilized in Japan and the warmer parts of China and is also referred to as *elephant yam* in these areas. Other common names include suran, whitempot giant arum, elephant bread, sweet yam, and stink lily (Kay 1987). *Amorphophallus* is native to tropical Southeast Asian and probably Africa (Kay 1987). It grows in the wild in the Philippines, Malaysia, Indonesia, and other Southeast Asian countries. It is not a true yam, but is more closely related to *Colocasia esculenta*, *Alocasia macrorrhiza* and *Cyrtosperma chamissonis*. It is a robust herbaceous perennial with an erect solitary stem usually 1–2.5 m high and bearing at the top one or two tripartite leaves, each part of which is deeply dissected into numerous segments. Towards the end of the plant's cycle (usually 4–6 years) a large terminal inflorescence is produced, consisting of a short stalk, a spathe and a spadix that emits a malodorous smell, reminiscent of rotten meat. It produces a large globose corm that is usually brownish-yellow to dull yellow in colour surrounded

by up to 10 cormels. Corms can weigh up to 9 kg (Kay 1987). She also reported that *A. paeoniifolius* had the following composition of the edible portion of the corms: energy approximately 330 kJ 100 g⁻¹, water 72–79%, carbohydrate 18–24%, protein 1.7–5.1%, fat 0.2–0.4%, fibre 0.8%, ash 0.7–1.3%, calcium 50–56 mg 100 g⁻¹, iron 0.6–1.4 mg 100 g⁻¹, phosphorus 20–53 mg 100 g⁻¹, vitamin A 434 IU 100 g⁻¹, thiamine 0.04–0.06 mg 100 g⁻¹, riboflavin 0.05–0.08 mg 100 g⁻¹, niacin 0.07–0.075 mg 100 g⁻¹ and ascorbic acid trace to 3 mg 100 g⁻¹. About 75–80% of the carbohydrate is starch. *A. konjac* was reported to have a water content of 80–90% with only about 10% of the carbohydrate as starch but up to 65% as glucomannan. *A. paeoniifolius* and *A. konjac* contain calcium oxalate crystals, and the wild forms of *A. paeoniifolius* contain more than the cultivated forms and are strongly acid.

Kay (1987) found that the growth cycle of the corms is 8–12 months, but it takes 3–4 seasons for an economically viable crop to be produced. At the end of each growth cycles the leaves wither and die, and this is indicative of the time to harvest. They are dug by hand. They are carefully cleaned after harvest and stored in heaps, preferably in a well-ventilated shed. *A. paeoniifolius* can be stored for several months at 10 °C (Kay 1987). Sprouting of *A. paeoniifolius* tubers for propagation was induced by storage in diffused light and by presoaking in aqueous solutions of gibberellic acid, Ethrel or thiourea. Thiourea was most effective in breaking dormancy with 92% sprouting in 75 days compared to 18% sprouting in the control. Darkness had a negative effect on sprouting (Kumar *et al.* 1998).

Endive

Compositae

Cichorium endiva L. Other common names include escaroles and frisee. Endive and chicory are often confused, but *C. endivia* is quite different in structural appearance from Witloof chicory (*C. intybus*). *C. endivia* is always marketed in the headed form; the larger heads weighing more than ½ kg. The heads are low spreading and loose leaved. The leaves vary from deeply cut and deeply curled in some cultivars to the broad, slightly cut and curled leaves. The outer leaves are green, and the centre leaves or heart and

Table 62 The composition of endive for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.79 g	Thiamine	0.080 mg
Energy	17 kcal	Riboflavin	0.075 mg
Protein	1.25 g	Niacin	0.400 mg
Total lipid (fat)	0.20 g	Vitamin B-6	0.020 mg
Carbohydrate, by difference	3.35 g	Folate	142 µg_DFE
Total dietary fibre	3.1 g	Vitamin B-12	0.00 µg
Sugars, total	0.25 g	Vitamin A	108 µg_RAE
Calcium	52 mg	Vitamin A	2167 IU
Iron	0.83 mg	Vitamin E (α-tocopherol)	0.44 mg
Magnesium	15 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	28 mg	Vitamin D	0 IU
Potassium	314 mg	Vitamin K (phyloquinone)	231.0 µg
Sodium	22 mg	Fatty acids, total saturated	0.048 g
Zinc	0.79 mg	Fatty acids, total monounsaturated	0.004 g
Total ascorbic acid	6.5 mg	Fatty acids, total polyunsaturated	0.087 g

the midribs are pale green to creamy white. *C. intybus* is sometimes marketed as blanched heads, greens or roots. Witloof chicory is commonly forced and can be identified by its very small, elongated, compact, well-blanched head that resemble a small shoot and weigh about 50 g. Witloof chicory is also grown for greens. It is probably native to the Mediterranean region, but it has also been reported to have originated in India (Purseglove 1972).

It is an annual or biennial herb and the edible part is the leaves, which are grown like spinach, and is sown and harvested in the open the same year. In some of the older cultivars the leaves tend to be bitter and were often covered with soil to blanch them to a pale yellow colour before harvesting. This blanching process takes from 5 to 20 days depending on the weather conditions. The curled endive will freeze at about -0.8 to -0.4 °C (Wright 1942). Weichmann (1987) differentiates the freezing point as -0.78 to -0.17 °C for endive and -0.89 to -0.06 °C for escarole. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 62.

At room temperature of 20 °C and 60% r.h. they could be kept for about 1½ days (Mercantilia 1989). Refrigerated storage recommendations were:

- 0 °C and 90–95% r.h. for 2–3 weeks (Wardlaw 1937, Hardenburg *et al.* 1990, Phillips and Armstrong 1967).
- 0–1 °C and 90–95% r.h. for 2–3 weeks (Endive) (Anonymous 1967).
- 0 °C and 95–100% r.h. for 14–21 days (Endive, Escarole) (SeaLand 1991).
- 2.2 °C and 95–98% r.h. for 14–28 days (Belgium Endive) (SeaLand 1991).
- 0 °C and 90–95% r.h. for 14 days (Mercantilia 1989).
- 4 °C for 8 days (Mercantilia 1989).
- 8 °C for 4 days (Mercantilia 1989).
- 0–1 °C and 95–100% r.h. for 2–3 weeks (Snowdon 1991).

Controlled atmosphere storage in 25% CO₂ was not recommended as it could cause the central leaves to turn brown (Wardlaw 1937).

When endive was packed on polystyrene trays in LDPE bags or P-Plus PE coverings its quality was still commercially acceptable after 3 weeks of storage at 5 °C. Those covered with vinyl film (called Borden Vinilo) had the lowest microbial counts with *Pseudomonas* and enterobacteria being the principal microbial contaminants (Venturini *et al.* 2000). Charles *et al.* (2005) stored endive at 20 °C in LDPE bags, which achieved a 3% O₂ + 5% CO₂ equilibrium atmosphere after 25 h of storage with an O₂ absorbing packet compared with 100 hours without the O₂ absorbing packet. After 312 h of storage in both packages the total aerobic mesophile, yeast and mould population growth were reduced compared to those in macroperforated OPP bags, which maintained gas composition close to that of air, but it also limited water loss.

Ensete

Musaceae

Ensete ventricosum (Welw.) Cheesman is synonymous with *E. edule*, *Musa ensete*, *M. arnoldiana* and *M. ventricosa*. Other common names include Abyssinian banana, enset, Ethiopian banana and false banana. *Ensete* is a perennial herbaceous monocot banana-like plant that normally grows to 4–8 m high and even sometimes up to 11 m in height (Tesfaye and Kebede 2006). The fruits are small and contain

seeds. Purseglove (1972) reported that it probably originated in Asia and spread to Africa in geological time and is now cultivated in East Africa, from Ethiopia to Angola between 1400 and 3100 m. Ensete grows best at elevations between 2000 and 2750 m not because it cannot withstand heat but because it needs adequate moisture. It is only grown as a crop in Ethiopia, where it has been eaten for thousands of years and it is a widely used staple food. In south and southwestern Ethiopia, it is the most important staple food crop. It has acquired a special place in the rainfed areas because of its drought tolerance (Taye and Asrat 1966, Westphal 1977). In Ethiopia ensete has many uses and nothing will be left from the plant. It can be a dependable source of income, therefore farmers in ensete-growing areas describe its importance by saying that 'it is everything for us: our food, clothes, beds, houses, cattle feed and plates'. The three major products utilized as food are commonly known as kocho, bulla and amicho (Taye and Asrat 1966, Westphal 1977, Ademasu and Westphal 2002).

Kocho or kojo is a fermented product from the scrapped parenchymatic tissue of pseudostem and pulverized corm. The pulp is extracted and placed in a circular pit about 1 m in diameter and 1 m deep lined with ensete leaves. When full it is covered over with leaves and weighed down with stones and left to ferment. After 3 or 4 weeks the pit is opened and some strongly fermented ensete from an older pit is added to accelerate the fermentation. After a further period of 4 weeks the pit is opened again and the contents rearranged and the pit reclosed, the total fermentation time taking from a few weeks to several months and sometimes for example in Ethiopia for up to a year (Westphal 1977). The fermented product is mixed with spices and used for making bread which is generally baked on iron griddles or clay pans over a fire. However, in one district the spiced dough is wrapped in leaves and put in a pit about 80 cm in diameter and 80 cm deep and covered with layers of soil and ensete leaves, on top of which the fire is kept burning for at least 12 h. Bulla or Boulla is made by dehydrating the juice arising from the mixture of scraped parenchymatic tissue of pseudostem, pulverized corm and granted stalk of inflorescence from which the juice is pressed and the residue then dehydrated. This is

then packed in ensete leaves and left in a silo for fermentation after which it is eaten as porridge. Amicho is the stripped corm of younger plants of ensete which is boiled and consumed in a similar way to potato (*Solanum tuberosum*), sweetpotato and cassava. The starchy endosperm of the hard seeds is also consumed.

False yam

Icacinaceae

Icacina senegalensis A. Juss. It is indigenous to West and Central Africa and is found growing wild on light sandy soils in the savannah areas of Senegal, Gambia, northern Ghana, Guinea and parts of the Sudan. It is a common weed in many savannah areas of West Africa, particularly where the true yam (*Dioscorea* spp.) has been cultivated. The tubers are used mainly as a famine food and sometimes as a source of starch or flour. In western Ashanti the tubers are reported to be used medicinally. The fruits are often eaten by children and the seeds are sometimes dried and pounded to yield flour, especially at times of food scarcity (Kay 1987). False yam is a shrubby perennial, variable in form, which produces glabrous or pubescent erect leafy shoots from a large, underground fleshy tuber. The aerial stems are light green, which may reach about 1 m in height. The flowers are inconspicuous, usually white or cream and pedunculate, ascending or erect, corymbose cymes, collected into a terminal leafless panicle, or the lower peduncles arising from the axis of reduced leaves. The fruit is a bright-red ovoid berry, up to 3 cm in length and 2.5 cm in width, containing a thin layer of white pulp surrounding a single spherical or ovoid seed. The tubers are variable in size from 30 to 100 cm with a diameter of about 30 cm and weighing up to 25 kg. They are greyish with a thin skin enclosing white flesh, which is usually speckled with yellow spots and they contain a bitter toxic principle. For consumption the tubers are cut up and placed in clean running water for several days, to remove the bitter principle and to facilitate maceration. They are then dried, pulverized and sieved to give greyish-white or creamy-yellow flour. The yield of the flour from the raw tuber is approximately 8–10%. The tubers contain about 10–15% of starch, the grains of which are irregular in shape, some spherical and some elliptical, with lengths varying

from 12 to 50 μm . Flour manufactured from the tubers has the following approximate composition: water 11.7%, protein 10.3%, fat 0.7%, carbohydrate 74.5%, ash 2.8%, calcium 150 mg 100 g⁻¹, iron 7 mg 100 g⁻¹, thiamine 0.04 mg 100 g⁻¹, riboflavin 0.18 mg 100 g⁻¹ and niacin 1.4 mg 100 g⁻¹. In addition, a bitter toxic principle, reported to be a gum resin, is present in quantities ranging from 0.9 to 2.8% (Kay 1987). The tubers are harvested by hand as required. Owing to their size and the fact that they can penetrate to about 25–30 cm below the surface they are difficult to dig out and at one time the plant was called abub ntopé (break hoe) in northern Ashanti.

Fenugreek

Fabaceae

Trigonella foenum-graecum L. Other common names include methi, methii, menthiyam and menthya. It is thought to have originated in the Middle East, and seeds have been found in archaeological sites in Iran dating back to 4000 BCE. Major fenugreek-producing countries include Argentina, Bangladesh, China, Egypt, France, India, Morocco, Pakistan, Spain and Turkey. The seeds are traditionally used to treat disorders such as diabetes, high cholesterol, wounds, inflammation and gastrointestinal ailments and may possess anticarcinogenic potential (Raju *et al.* 2004). It is an annual plant that has small round leaves, which is cultivated worldwide as a semi-arid crop grown for its leaves that are used like spinach. It was reported by Waskar *et al.* (1998) that in India its storage life was increased from 1 day at room temperature of 17–30 °C and 24–73% r.h. to 6½ days in 50 μm PE bags of and 2% ventilation in storage at 8 °C and 90–92% r.h. Brar *et al.* (2011) stored leaves in 35 μm PP film bags, with two perforations of 0.3 mm in each bag. Other treatments were with and without 10 g of mustard seeds as natural absorbents as well as in non-perforated PP film bags with and without mustard seed. They were stored at 15 °C and 75% r.h. for 6 days. They found that among the treatments they tested, packaging of fenugreek in bags with two perforations with mustard seeds resulted in best maintenance of chlorophyll, ascorbic acid, phenols and aroma.

Fig leaf gourd

Cucurbitaceae

Cucurbita ficifolia Bouché also called Malabar gourd. It has been cultivated in the highlands of Central and South Americas since ancient times. Remains have been found at Huaca Prieta in Peru dating to 3000–4000 BCE. It is a vigorous perennial monoecious climber whose fruit is an edible oval berry up to 20 cm long with a green skin with a white striped or blotched design. The flesh contains numerous large black seeds that may be used in cookery as flavouring (Smith 1936, Purseglove 1968). It can also be candid or fermented to produce a beverage. The only reference to its postharvest life is that the fruits can be stored for long periods (Smith 1936).

Five-leaf yam

Dioscoreaceae

Dioscorea pentaphylla L. At least two varieties have been identified *D. pentaphylla* var. *palmata* and *D. pentaphylla* var. *papuana* (Barrau 1956) or three varieties *D. pentaphylla* var. *javanica*, *D. pentaphylla* var. *malaica* and *D. pentaphylla* var. *sacerdotalis* (Burkill 1951). It may sometimes be confused with *D. cumingii*, which is used as a food in the Philippines to a limited extent (Burkill 1951). Shajeela *et al.* (2011) referred to *D. pentaphylla* var. *pentaphylla*. It is native to tropical Asia or eastern Polynesia and was first brought into cultivation somewhere in the Indo-China peninsula and is now cultivated throughout the Pacific Islands and Indonesia (Coursey 1967). Sturtevant (1892) stated 'Tropical Asia. In India, this yam is common in jungles and is found in the South Sea Islands. Wight (1840–1853) has never seen it cultivated in India, although the natives dig the tubers to eat. It is cultivated in Amboina and sometimes in Viti. In India, the male flowers are sold in the bazaars and eaten as greens. The tubers are eaten in Viti and Hawai'i. It is a good yam. Graham says the tubers are dreadfully nauseous and intensely bitter even after being boiled. They are put into toddy to render it more potent, as they have intoxicating properties, and a few slices are sufficient. In China, the nauseous tubers are sometimes cooked and eaten.' In Indonesia and Oceania the tubers are often collected from wild plants. They are also used as hedges on farms,

which can form a reserve of food for times of scarcity (Coursey 1967, Purseglove 1972). It is a prickly vine that may reach 10 m in length that grows from a long, cylindrical basal tuber. The tubers are dark brown in colour with a smooth surface and white flesh and grow laterally. They are up to 60 cm long and 6–8 cm in diameter. The tubers may weigh over 1 kg and can be formed over a meter underground. The vines produce horseshoe-shaped bulbils about 1 cm long and new plants can also sprout from the bulbils. Bulbils can also be cooked and eaten.

Mohan and Kalidass (2010) reported that the chemical content of the tubers was 93.05% moisture, 15.88 ± 0.07 starch, 9.18 ± 0.18 crude protein, 4.8 ± 0.02 crude lipid, 5.14 ± 0.11 crude fibre, 4.64 ± 0.02 ash, 76.23 nitrogen-free extractives, 18.82 ± 0.11 niacin and ascorbic acid 4.59 ± 0.24 g 100 g^{-1} , and its calorific value is $1607.47 \text{ g } 100 \text{ g}^{-1}$ (kJ 100 g^{-1} dry matter). They also gave *in vitro* protein digestibility as 4.87% and *in vitro* starch digestibility as 86.14%. Shajeela *et al.* (2011) gave the following analysis for *D. pentaphylla* var. *pentaphylla*: starch 55.98 ± 0.51 g 100 g^{-1} , niacin 62.14 ± 0.14 g 100 g^{-1} and ascorbic acid 96.56 ± 0.34 g 100 g^{-1} . Mohan and Kalidass (2010) also identified its anti-nutritional factors as total free phenolics 0.75 ± 0.06 g 100 g^{-1} , tannins 0.44 ± 0.06 g 100 g^{-1} , hydrogen cyanide 0.09 ± 0.03 mg 100 g^{-1} , total oxalate 0.31 ± 0.01 g 100 g^{-1} , amylase inhibitor 1.95 AIU mg soluble starch $^{-1}$ and Trypsin inhibitor 2.86 TIU mg protein $^{-1}$. Shajeela *et al.* (2011) gave the following analysis for anti-nutritional factors for *D. pentaphylla* var. *pentaphylla*: total free phenolics 0.48 ± 0.05 g 100 g^{-1} , tannins 0.09 ± 0.06 g 100 g^{-1} , hydrogen cyanide 0.18 ± 0.01 mg 100 g^{-1} , total oxalate 0.58 ± 0.05 g 100 g^{-1} , amylase inhibitor 2.46 AIU mg $^{-1}$, soluble starch and trypsin inhibitor 3.66 ± 0.09 TIU mg $^{-1}$ protein. However, Coursey (1967) reported that tubers are hardly, if at all, toxic. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 63.

Garlic

Alliaceae, Liliaceae

Allium sativum L. USDA (2013) gave the following:

- Bear garlic *A. ursinum* L.

Table 63 The composition of mountain yam (*Dioscorea pentaphylla*) from Hawaii for 100 g^{-1} fresh weight (source: adapted from USDA 2012a)

Water	81.44 g	Thiamine	0.102 mg
Energy	67 kcal	Riboflavin	0.019 mg
Protein	1.34 g	Niacin	0.481 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.179 mg
Carbohydrate, by difference	16.31 g	Folate	14 μg _DFE
Calcium	26 mg	Vitamin B-12	0.00 μg
Iron	0.44 mg	Vitamin A	0 μg _RAE
Magnesium	12 mg	Vitamin A	0 IU
Phosphorus	34 mg	Vitamin D (D2 + D3)	0.0 μg
Potassium	418 mg	Vitamin D	0 IU
Sodium	13 mg	Fatty acids, total saturated	0.022 g
Zinc	0.27 mg	Fatty acids, total monounsaturated	0.004 g
Total ascorbic acid	2.6 mg	Fatty acids, total polyunsaturated	0.045 g

- Black garlic *A. nigrum* L.
- Daffodil garlic *A. neapolitanum* Cirillo
- Field garlic *A. oleraceum* L.
- Fragrant false garlic *Nothoscordum borbonicum* Kunth
- Fraser meadow garlic *A. canadense* L. var. *fraseri* Ownbey
- Hyacinth meadow garlic *A. canadense* L. var. *hyacinthoides* (Bush) Ownbey & Aase
- Meadow garlic *A. canadense* L., *A. canadense* L. var. *ecristatum* (M.E. Jones) Ownbey, *A. canadense* L. var. *canadense*, *A. canadense* L. var. *lavandulare* (Bates) Ownbey & Aase, *A. canadense* L. var. *mobilenae* (Regel) Ownbey
- Striped garlic *A. cuthbertii* Small
- White garlic *A. neapolitanum* Cirillo
- Wild garlic *A. vineale* L., *A. vineale* L. ssp. *vineale*.

It is thought to be a cultivated race of Central Asian origin, and its use as flavouring for foods dates back to ancient Egypt. Garlic is among the oldest known horticultural crops. Egyptian and Indian cultures referred to garlic 5000 years ago, and there is historical evidence for its use by the Babylonians 4500 years ago and by the Chinese 2000 years or even for 4000 years ago. The edible part is made up of a cluster of small bulbs, called cloves, which are enclosed in white or pink papery skin. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 64. Total world

Table 64 The composition of garlic bulbs for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	58.58 g	Thiamine	0.200 mg
Energy	149 kcal	Riboflavin	0.110 mg
Protein	6.36 g	Niacin	0.700 mg
Total lipid (fat)	0.50 g	Vitamin B-6	1.235 mg
Carbohydrate, by difference	33.06 g	Folate	3 µg_DFE
Total dietary fibre	2.1 g	Vitamin B-12	0.00 µg
Sugars, total	1.00 g	Vitamin A	0 µg_RAE
Calcium	181 mg	Vitamin A	9 IU
Iron	1.70 mg	Vitamin E (α-tocopherol)	0.08 mg
Magnesium	25 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	153 mg	Vitamin D	0 IU
Potassium	401 mg	Vitamin K (phyllloquinone)	1.7 µg
Sodium	17 mg	Fatty acids, total saturated	0.089 g
Zinc	1.16 mg	Fatty acids, total monounsaturated	0.011 g
Total ascorbic acid	31.2 mg	Fatty acids, total polyunsaturated	0.249 g

production in 2010 was estimated by FAO (2012) as 22,561,298 tonnes.

Harvesting and handling

Unlike other *Allium* spp. the bulbs are produced entirely underground. Harvest maturity is when the leaves die back and wither or when the tops become partly dry and bend to the ground. It has also been suggested to wait until the lower third to half of the leaves have turned brown, but there are still mostly green leaves higher on the plant. In some cultivars harvesting is judged to be when the hard neck scapes are standing straight up but before the pods containing the bulbils open up.

They are harvested by pulling the tops and levering with a fork inserted in the soil just below the bulbs. Garlic must be undercut or dug since it will not readily pull up out of the ground, even at full maturity. Mechanical harvesters that have been developed for bulb onions (*A. cepa*) can be used for garlic with only a slight adjustment to the cutting depth. Garlic may be dug up with a simple potato digger and windrowed on the soil surface for a 1–2-day curing period, then placed into sacks or bins and left in the field for final curing taking 10–14 days or as long as needed. Garlic

must be protected from sun scald especially during periods of high temperature over 30 °C and bright sunlight. Excessive exposure to sunlight may also result in greening (Oregon State University 2005). In the cultivar Eusung, clipping the stems to 5 or 10 cm before harvesting reduced sprouting, incidence of brown spotty disorder and weight loss during 7½ months of storage at 0 °C compared to those stored without clipping (Park and Jung 2000). In Mexico garlic is a major export crop and they are harvested into plastic boxes and taken to packhouses for drying, grading and packing for export (Figure 33). It is an important crop in Yemen, and Figure 34 shows local farmers grading garlic for the local market. Pre-cooling is not common but Holmes and Kemble (2009) recommended room cooling for garlic grown in the southern United States.



Figure 33 Packing garlic for export in Mexico. See colour plate section.



Figure 34 Grading garlic for market at a farm in Hadramaut in Yemen.

Sprouting

Garlic will eventually lose dormancy, signalled by internal development of the sprout. This occurs most rapidly at intermediate storage temperatures of 5–18 °C (Oregon State University 2005). Maleic hydrazide at 15 L ha⁻¹ applied 2 weeks before harvest or irradiation with 60 Gy using Co⁶⁰ γ rays 30 days after harvest were used to control sprouting (Pellegrini *et al.* 2000). However, maleic hydrazide is banned in some countries and there is some consumer resistance to irradiation.

Postharvest physiology

It has low ethylene production and low sensitivity to external ethylene. Respiration rate, in watts tonne⁻¹, was given as 10–30 at 0 °C, 17–40 at 5 °C, 25–56 at 10 °C, 37–76 at 15 °C and 42–90 at 20 °C (SPLFS 2001).

Storage

Garlic must be dry and free from condensation and any other surface water before being placed in storage. At tropical ambient temperatures of 27–32 °C and less than 70% r.h. they can be stored for up to 30 days (Tindall 1983). At simulated room temperature of 20 °C and 60% r.h. they could be stored for 3–4 weeks (Mercantilia 1989). At ~20 °C they could be stored for 21–28 days (SPLFS 2001). In temperate countries such as the United States they are commonly stored in dry well-ventilated sheds over winter for up to 4 months (Lutz and Hardenburg 1968), and this practice still exists. The cloves will freeze at about –4.1 to –3.5 °C (Wright 1942) or –3.39 to –0.83 °C (Weichmann 1987), but McGuire (1929) reported that dried bulbs will tolerate temperatures as low as –6 °C. However, such a low temperatures is not commonly used commercially for storage of fresh garlic. High humidity in the storage will favour mould growth and rooting. Garlic odour is easily transferred to other products so they should be stored separately (PTRIC 2005). Refrigerated storage recommendations include:

- 0 °C and 85–90% r.h. for 1–3 months (Wardlaw 1937).
- 0 °C and 70–75% r.h. for 6–8 months (Wardlaw 1937, Phillips and Armstrong 1967).

- –1.5 to 0 °C and 70–75% r.h. for 6–8 months (Anonymous 1967).
- 0 °C and 70–75% r.h. for 3–4 months (Lutz and Hardenburg 1968).
- 0 °C and 65% r.h. for 28–36 weeks with 12.6% loss (Pantastico 1975).
- 0 °C and less than 70% r.h. for up to 150 days (Tindall 1983).
- 0 °C and 70% r.h. they could be stored for 6–7 months (Mercantilia 1989).
- 0 °C and 65–70% r.h. for 6–7 months (Hardenburg *et al.* 1990).
- 0 °C and 65–70% r.h. (SeaLand 1991).
- 0 °C and 70% r.h. for 6–8 months (Snowdon 1991).
- 0 °C and 65–70% r.h. for 180–210 days (SPLFS 2001)
- –1 to 0 °C and 60–70% r.h. for more than 9 months (Volk and Rotindo 2004).
- 0 °C and 65–70% r.h. for 6–7 months (Oregon State University 2005).
- –1° to 0 °C with 60–70% r.h. for more than 9 months (PTRIC 2005).
- 0 °C with 65–70% r.h. for 6–7 months garlic grown in the southern United States (Holmes and Kemble 2009).

Controlled atmosphere storage

Controlled atmosphere storage was recommended at 0 °C with 0% CO₂ and 1–2% O₂ (SeaLand 1991), and Monzini and Gorini (1974) recommended 3 °C in 5% CO₂ + 3% O₂ for 6 months. PTRIC (2005) reported that storage at 0–5 °C in 5–15% CO₂ retarded sprout development and decay, but 15% CO₂ may result in some yellow translucent discolouration on some cloves after about 6 months of storage. Low O₂ at 0.5% did not retard sprout development of the cultivar California Late stored for up to 6 months at 0 °C. SPLFS (2001) recommended 1–2 °C with 1–2% O₂ and 0–10% CO₂ which will give an additional storage period of 30 days compared to storage in air at the same temperature. Cantwell *et al.* (2003) showed that storage of the cultivars California Late and California Early at 0–1 °C in CO₂ atmospheres of 5, 10, 15 and 20% reduced sprout growth, decay and discolouration but CO₂ concentrations over 15% could lead to injury after 4–6 months. For fresh peeled garlic they found that storage at 5 and 10 °C and 5–15%, CO₂ or 1–3% O₂ was effective in retarding

discolouration and decay for 3 weeks. Garlic shoots were stored at 0 °C in 10 combinations of 3–6.5% O₂ + 0–12% CO₂. Zhou *et al.* (1992b) found that the optimum atmosphere was 3% O₂ + 8% CO₂, which maintained levels of chlorophyll, reducing and total sugars and freshness of the flower buds after 235 days. However, there was some spoilage and rotting but rotting decreased with decreasing O₂ concentration, while high CO₂ reduced mould growth. Zhou *et al.* (1992a) and Zhang and Zhang (2005) used CA storage of sprouted garlic in chambers flushed with N₂ from a carbon molecular sieve to reduce the O₂ content to 1–5%. CO₂ was allowed to increase to 2–7% by product respiration. After 240–270 days the quality of sprouted garlic remained high. After fumigating, the shoots were treated with a fungicide and packed in plastic bags with a silicon window and stored at 0–1 °C with 95% r.h. These treatments reduced the respiration rate and the loss of chlorophyll and inhibited cellulose production. After 280 days 96% had good freshness, greenness and crispness.

Modified atmosphere packaging

Since optimum humidity for storage is around 70% r.h. storage in plastic bags is usually not suitable. However, Lee and Lee (1996) used LDPE film of 27 µm thickness for the preservation of a mixture of carrot, cucumber, garlic and green peppers. The steady state atmosphere at 10 °C inside the bags was 5.5–5.7% CO₂ and 2.0–2.1% O₂.

Storage for planting

Optimum storage temperature for cloves for planting was 10 °C with 65–70% r.h. but they will sprout rapidly between 4 and 10 °C, therefore prolonged storage at this temperature range should be avoided. Storage of planting stock at temperatures below 4 °C results in rough bulbs, side-shoot sprouting (witches-brooming) and early maturity, while storage above 18 °C resulted in delayed sprouting and late maturity (SPLFS 2001). In California, where considerable garlic is grown, it is frequently put in common storage for 3–4 months or sometimes longer if the building can be kept cool, dry and well ventilated (Oregon State University 2005).

Gherkin

Cucumis sativus L. They are cultivars of the same species as cucumber and gherkin is a term generally used to refer to a savoury pickled cucumber particularly in Europe. Purseglove (1972) reported that they originated in northern India. The name gherkin can also refer to the West Indian burr gherkin (*Cucumis anguria* L.) that originally from West Africa. It is also edible and may be pickled, but becomes bitter and spiny if allowed to grow larger than 4 cm long. Total world production for cucumbers and gherkins in 2010 was estimated by FAO (2012) as 62,430,796 tonnes.

Harvesting

They are usually harvested when they are 4–8 cm long and pickled in jars or cans with vinegar, often flavoured with herbs particularly dill, or in brine. Gracelin *et al.* (2012) reported that gherkins for pickling should be used as soon as possible after harvesting and certainly within 24 h. They also reported that in India the gherkins are graded by their diameter and length, with 1–4 cm long being the best grade that commands the highest price and other grades are 3–6, 6–9 and 9–12 cm long commanding progressively lower prices.

Ginger

Zingiberaceae

Zingiber officinale Rosc. It is a native of Asia where has been grown in mild climates since ancient times from where it has been exported to Europe in its dried form for centuries (Purseglove 1972). It is a perennial herb with a fleshy rhizome that is used as a spice and as a preserve. It is sold fresh, but also as preserved ginger, crystallized ginger and dried ginger. It also has medicinal properties. Ginger contains up to 3% of a fragrant essential oil whose main constituents are sesquiterpenoids. The pungent taste of ginger is due to non-volatile phenylpropanoid-derived compounds, particularly gingerol, an oleoresin combination of volatile oils and resin, and shogaols, which form from gingerols when ginger is dried or cooked. Components of gingerol (zingiberone, bisabolene, camphene, geranial, linalool and borneol) possess

beneficial properties for the treatment various human disorders (Dubey and Tiwari n.d.). Gingerol has been shown to have preventative and control effects on cancer and other human diseases. [6]-gingerol (1-[4'-hydroxy-3'-methoxyphenyl]-5-hydroxy-3-decanone) is the major pungent principle of ginger (O'Hara *et al.* 1998, Oyagbemi *et al.* 2010). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 65. Total world production of ginger in 2010 was estimated by FAO (2012) as 1,682,998 tonnes. Anand (1982) reported that besides fresh ginger it is also marketed as preserved ginger – prepared at 5–7 months, peeled, cut into pieces impregnated with sugar syrup. Also essential oil and oleoresin are extracted. It is also marketed as several other products:

- Peeled, scraped or uncoated – cork skin cleanly removed without damage to the underlying tissue
- Rough scraped – cork skin partly removed, usually only on one side
- Unpeeled or coated – skin remains intact
- Black ginger – scalded 10–15 min in boiling water and dried
- Bleached or limed – peeled and treated with lime and sulphurous acid
- Split or sliced – unpeeled or unscraped but longitudinally split or sliced
- Ground – dried and ground into a powder.

Harvesting

They are harvested some 9–10 months after planting when the leaves begin to turn yellow and the stems fall down (Purselove 1972). However, for fresh products and preserves, Sutarno *et al.* (1999) recommended harvesting before they are fully mature while they are still tender and have low pungency and fibre. Okwuowulu and Nnodu (1988) from experiments also found that rhizomes harvested 6 months after planting were most suited to prolonged storage in moist sawdust. For making preserved ginger they are harvested immature so that they have no fibres and have a milder flavour. Therefore the optimum harvest time for fresh consumption is about 5 months, for preserved ginger 5–7 months, for dried ginger 8–9 months (when leaves start turning yellow) and for essential oil production 8–9 months. In many countries ginger is harvested mechanically

Table 65 The composition of ginger for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	78.89 g	Thiamine	0.025 mg
Energy	80 kcal	Riboflavin	0.034 mg
Protein	1.82 g	Niacin	0.750 mg
Total lipid (fat)	0.75 g	Vitamin B-6	0.160 mg
Carbohydrate, by difference	17.77 g	Folate	11 µg_DFE
Total dietary fibre	2.0 g	Vitamin B-12	0.00 µg
Sugars, total	1.70 g	Vitamin A	0 µg_RAE
Calcium	16 mg	Vitamin A	0 IU
Iron	0.60 mg	Vitamin E (α-tocopherol)	0.26 mg
Magnesium	43 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	34 mg	Vitamin D	0 IU
Potassium	415 mg	Vitamin K (phyloquinone)	0.1 µg
Sodium	13 mg	Fatty acids, total saturated	0.203 g
Zinc	0.34 mg	Fatty acids, total monounsaturated	0.154 g
Total ascorbic acid	5.0 mg	Fatty acids, total polyunsaturated	0.154 g

(Baranowski 1986, Weiss 2002). In Guyana delaying harvest until all of the leaves have died was not recommended as it reduced rhizome quality, increase fibre content, decrease storage life and increase the incidence of sprouting (Anonymous 2004). Also in Guyana it was recommended to avoid leaving the rhizomes exposed to direct sun for longer than 30 min. The harvested ginger should be placed directly into strong well-ventilated wooden or plastic field crates. Transporting ginger in mesh sacks increased the level of skin damage owing to rubbing of the delicate skin against the mesh. Harvesting during very wet or very dry conditions is not desirable as this will increase the amount of skinning and make removal of the rhizomes from the soil much more difficult.

Irradiation

Irradiation at 0.05–0.06 kGy may be used to inhibit sprouting and extend shelf life of fresh ginger (Wu and Yang 1994, Mukherjee *et al.* 1995). However, irradiation at these low levels decreased volatile content of fresh ginger, which was perceived by sensory analysis after 5 months of storage (Wu and Yang 1994). Irradiation of dried rhizomes at doses of 5–10 kGy

prevented mould and bacteria growth (Dubey and Tiwari n.d.).

Curing

Ginger intended for storage should be cured by air drying the rhizomes at ambient temperature of 22–26 °C and 70–75% r.h. for several days to allow the skin to thicken and the cut surfaces to suberize. Curing will help reduce postharvest weight loss and decay. Following curing, the ginger should be put in well-ventilated containers for long-term storage (Anonymous 2004).

Sprouting

Sprouting of ginger rhizomes may begin after several weeks at ambient temperature. They will sprout at temperatures above 15.6 °C, and the rate of sprouting increases as the storage temperature increases. Storage at 12.5 °C will prevent sprouting, but there is no effective chemical sprout inhibitor for ginger.

Storage

In some parts of India they are stored over winter in pits (Dohroo 2001). A high storage humidity gives rise to mould growth (Lutz and Hardenburg 1968) which is why Akamine (1962) recommended storage in 65% r.h. In spite of this some sources recommend storage in humidity as high as 90% r.h. Akamine (1962) also reported that room temperature desiccation and sprouting limited storage to only 1 month. Ginger rhizomes are very sensitive to chilling injury if stored below 12 °C, which results in pitting and sunken lesions on the rhizome surface, shrivelling, softening, flesh darkening and postharvest decay. Slight chilling injury may occur after 5 days at 7 °C and significant levels after 14 days. Cured rhizomes were less susceptible to chilling injury than those that had not been cured (Anonymous 2004). Akamine (1962) found that chilling injury could occur after 2 or 3 weeks exposure to 7.2 °C, the symptoms of which were softening, shrivelling and oozing of moisture particularly from the cut ends. Refrigerated storage recommendations for fresh ginger were:

- 12.8 °C and 65% r.h. for 6 months with 16.5% weight loss (Akamine 1962).

- 12.8 °C and 35% r.h. for 3 months with up to 16% weight loss (Akamine 1962).
- 1.5–3.5 °C and 85–90% r.h. for 15 weeks (Anonymous 1967).
- 7.2–10 °C and 75% r.h. for 16–24 weeks with 18.9% weight loss (Pantastico 1975).
- 12.5 °C and 90% r.h. for 28 weeks for Hawai'ian ginger as determined by changes in dry weight, fibre content, oil content, sugars and phenols (Paull *et al.* 1988).
- 22 °C and 70% r.h. for up to 20 weeks due to excessive water loss and fibre contents (Paull *et al.* 1988).
- 13 °C and 65% r.h. for 6 months with a loss of 16% (Lutz and Hardenburg 1968, Hardenburg *et al.* 1990).
- 13.3 °C and 85–90% r.h. for 90–100 days (SeaLand 1991).
- 13 °C and 70% r.h. for 4–6 months (Snowdon 1991).
- 10–12 °C and 90% r.h. (Dubey and Tiwari n.d.).

Dehydration occurs in storage in low humidity conditions, e.g. less than 65% r.h. Shrivelling becomes noticeable after the loss of more than 10% of the initial harvest weight, but surface mould will begin to grow at 90% r.h. or higher and sprouting will be stimulated, especially if the temperature is above 16 °C. In order to minimize weight loss but avoid surface mould, a compromise humidity range of between 70 and 75% r.h. was recommended. Ginger stored at 22 °C and 70% r.h. for 3 months will lose about 20% of its initial weight. Ethylene oxide at 50 µl L⁻¹ can be used as a fumigation treatment of rhizomes (Dubey and Tiwari n.d.).

Modified atmosphere packaging

Akamine (1962) found that storage in vented polyethylene bags could not be recommended unless a way was found to inhibit mould growth. A combination of biocontrol with *Trichoderma* sp. and storage in polyethylene bags at 25–30 °C controlled storage rot due to the fungus *Sclerotium rolfsii* and reduced weight loss (Mukherjee *et al.* 1995). The Indian Institute of Spices Research (n.d.) recommended storage of fresh ginger in PE bags with 2% ventilation that prevented both dehydration and mould development.

Transport

In shipments from Puerto Rico to the United States taking 9 days at 13 °C the rhizomes consistently arrived in good condition (Burton 1970).

Diseases

Pythium ultimum, *Fusarium oxysporum* and *Verticillium chlamydosporium* were associated with storage rots of ginger (Dohroo 2001). Blue mould, caused by *Penicillium* spp., is a common postharvest rot of ginger stored at a high humidity. Blue mould generally requires moisture condensation on the rhizome surface, or storage at a relative humidity above 95%. Mild surface infestations may be superficial only and not cause decay. However, the ginger has an unsightly appearance. Blue mould which develops on cut ends and injured areas will typically result in internal tissue decay. The rotted tissue is pale to dark brown and may be firm or soft. Decay is particularly rapid at temperatures between 15 and 20 °C. Overy and Frisvad (2005) found that *P. brevicompactum* was the predominant species isolated from 85% of 20 naturally infected ginger rhizomes that displayed visible mould growth. Mycophenolic acid is a potent immunosuppressant and was identified from corresponding tissue extracts. Dry rot, caused by the soil-borne fungus *Fusarium*, is a common postharvest disease of ginger. Infection is typically associated with wounds or insect and nematode-damaged tissue. External symptoms of dry rot include off-coloured dry sunken lesions on the rhizome surface. The lesions are typically bordered by a brown margin. The fungus subsequently invades the entire rhizome, which becomes brown, dry and shrivelled. In humid environments, the ginger surface may become covered with a dense white mould. Internal symptoms include a pale brown discolouration of the vascular tissue. Watery rot, caused by *Rhizopus*, is one of the most rapidly developing storage rots of ginger. Symptoms include a soft, watery rot that progresses rapidly and may rot an entire rhizome in a week. Infected tissue is mottled brown and soft, and in a humid atmosphere the infected area is soon covered with large amounts of white mould. The mould will eventually turn black. *Rhizopus* is a wound pathogen and is not effective in colonizing healthy

tissue. The postharvest treatment with Botran applied just prior to packing may reduce watery rot during transport to export market destinations. *Pythium* is another common soil-borne fungus that can be severe on ginger harvested during the rainy season or on rhizomes grown in poorly drained soils. Symptoms appear as small brownish spots on the skin, which may rapidly enlarge into sizeable lesions. As the decay progresses, the tissue breaks down into a soft and watery mass. Armillaria rot, caused by the fungus *Armillaria mellea*, can be a problem on ginger grown in recently cleared forest land. Symptoms include the development of tough, dark, string-like growths which adhere to the rhizomes. These structures are aggregations of fungal strands, commonly called the shoe-string fungus. Control involves the uprooting of all remaining tree stumps. Sclerotium rot, caused by the soil-borne fungus *Sclerotium rolfsii*, is most commonly found on rhizomes harvested from stressed plants. Symptoms of decay include a well-defined separation between rotted and healthy tissues. A white mould forms on the ginger surface and noticeable shrinkage of the rhizome occurs. Small spherical fungal resting bodies about 1–2 mm in diameter develop on the mould. They are initially white but later turn brown. Bacterial soft rot, caused by *Erwinia carotovora*, is the principal postharvest bacterial disease of ginger. These bacteria are widespread, especially in poorly drained soils, and enter the ginger rhizome via wounds in the tissue. Symptoms of bacterial soft rot include a soft wet rot of the tissue, which has a strong foul odour. Development of this disease is rapid under warm, humid conditions (Anonymous 2004, Dubey and Tiwari n.d.).

Pre-storage treatment with 0.2% Topsin M (thiophanate-methyl) and 0.2% Bavistin (carben-dazim) for 60 min reduced incidence of storage rot, loss in rhizome weight, surface shrivelling sprouting of ginger and increased the recovery of the rhizomes (Dohroo 2001). Postharvest applications of benomyl ($750 \mu\text{L}^{-1}$ a.i.) with gibberellic acid ($150 \mu\text{L}^{-1}$) was effective in controlling rotting and reducing weight loss and sprouting (Okwuowulu and Nnodu 1988). However, the postharvest use of chemicals may not be permitted in some countries. Benomyl use is not permitted in many countries. Singh *et al.* (2011) found that alcohol extracts at $3000 \mu\text{L}^{-1}$

showed almost 100% inhibition of activity *in vitro* on *Penicillium digitatum*, *Aspergillus niger* and *Fusarium* sp. isolated from naturally infected citrus fruit.

Giant taro

Araceae

Alocasia macrorrhiza (L.) G. Don. Other common names include alavu, ape, dokuimo, hog tannia, manaka and viamiloa. Kay (1987) reported that it is thought to have originated in Sri Lanka, but has become widely distributed in Malaysia, Indonesia and Polynesia and has spread to parts of tropical other parts of Southeast Asia and tropical America. It is a giant succulent herbaceous perennial plant, reaching up to 4.5 m in height. It produces a basal corm surrounded by smaller cormels. The fleshy aerial stems are also used as a vegetable (Coursey 1967, Kay 1987). The food value of the edible portion of the raw stem tubers of giant taro has been reported as: energy 293–599 kJ 100 g⁻¹, water 63–81%, crude protein 0.6–3.3%, fat 0.1–0.2%, carbohydrate 17–27%, ash 1.1–1.3%, calcium 46–153 mg 100 g⁻¹, iron 0.5–1 mg 100 g⁻¹, phosphorus 45–72 mg 100 g⁻¹, niacin 0.4 mg 100 g⁻¹, riboflavin 0.02–0.03 mg 100 g⁻¹, thiamine 0.09–0.1 mg 100 g⁻¹ and trace levels of ascorbic acid. Much of the calcium is in calcium oxalate crystals (Kay 1987). Their composition changes with age, with older material having lower moisture content and higher dry matter. Few figures have been published showing starch content but there may also be substantial quantities of other carbohydrates associated with it. Several cultivars are reported to contain cyanogenic glycoside in the young leaves and up to 0.018% hydrogen cyanide has been found, but it has not been reported in the corms or stems (Rashid and Daunicht 1979).

They can be stored in the ground and therefore harvesting can be anything between 9 months and 4 years (Bradbury and Holloway 1988), and Kay (1987) reported that they can remain in the ground for about 3 months after reaching maturity without any deterioration. In the South Pacific they may be stored in barns. The recommended refrigerated storage temperature was 5 °C but they can also be

stored for about 1 month at 15 °C (Bradbury and Holloway 1988).

Globe artichoke

Asteraceae, Compositae

Cynara spp. Two groups are recognized. The first is the globe artichoke *C. cardunculus* Scolymus Group, previously distinguished as *C. scolymus* L. or *C. cardunculus* L. var. *scolymus* (L.) Fiori that have been selected for their edible flower buds. The other is the cardoon *C. cardunculus* L. Cardoon Group, synonymous with *C. cardunculus* var. *altalis* DC that were selected mainly for edible leaf stems, but the flower buds can be eaten much as the globe artichoke (Sonnante *et al.* 2007). There is also the wild cardoon *C. cardunculus* var. *sylvestris* (Lamk.) Fiori. *C. cardunculus* Scolymus Group is also called artichoke and Italian artichoke, and *C. cardunculus* Cardoon Group is also called prickly artichoke, artichoke thistle, cardone and cardoon. It is native to the western and central Mediterranean regions, where it has been cultivated from ancient times. It was popular in Greek, Roman, and Persian cuisines and remained popular in medieval and early modern European cuisines, but they fell from fashion in the late 19th century. The wild cardoon is distributed over the west and central parts of the Mediterranean region from Portugal to Turkey, as well as the Canary Islands and Madeira. It has become a weed in parts of Argentina, Australia and the United States (Sonnante *et al.* 2007). Total world production of globe artichoke in 2010 was given by FAO (2012) as 1,449,395 tonnes.

For *C. cardunculus* Scolymus Group the edible portion is the immature flower, which is made up of the receptacle and the fleshy bases of involucre and called chokes (Figure 35). It is the fleshy bases that are eaten as a delicacy after cooking. It is produced on a low thistle-like plant. *C. cardunculus* Cardoon Group is a robust herbaceous perennial growing up to 2.5 m high forming a clump of silvery-grey, pinnatifid, spiny leaves up to 1 m in length and large thistle-like purple flowers. They are covered with small spines but several spineless cultivars have been developed. They will freeze at about –1.9 °C (Wright 1942) or –1.44 to –1.17 °C (Weichmann 1987). Leroy



Figure 35 Artichokes on a wholesale market in London in the United Kingdom.

et al. (2010) reported that they had about 50–70 g kg⁻¹ of their fresh weight as inulin-type fructan. They found that in storage at 18 or 4 °C either in PP film bags or with no packaging that there was a decrease in inulin content during storage and an average degree of polymerization, accompanied by an increase of free fructose and sucrose owing to depolymerization of inulin. During storage at higher temperatures and storage without packaging induced these carbohydrate changes. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 66.

Harvesting

They are harvested while still immature and tender; otherwise they tend to be tough and stringy. Wardlaw (1937) recommended harvesting them when they reach their maximum size before the lower bracts start to spread open or the internal flower parts develop. The primary and secondary buds mature at different times so they should be harvested every 5–7 days. Over mature buds can be bitter. The bud is cut with about 5–7 cm of stem attached but in Greece; the inflorescences are usually harvested together with 20–30 cm of the inflorescence stalk, tied in bundles and marketed within 1–2 days (Alexopoulos *et al.* 2003).

Pre-cooling

Hygrotech SA (2004) reported that artichokes cooled immediately after harvesting were of very good

Table 66 The composition of cardoon (*Cynara cardunculus*) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	94.00 g	Total ascorbic acid	2.0 mg
Energy	17 kcal	Thiamine	0.020 mg
Protein	0.70 g	Riboflavin	0.030 mg
Total lipid (fat)	0.10 g	Niacin	0.300 mg
Carbohydrate, by difference	4.07 g	Vitamin B-6	0.116 mg
Total dietary fibre	1.6 g	Folate	68 µg_DFE
Calcium	70 mg	Vitamin B-12	0.00 µg
Iron	0.70 mg	Vitamin A	0 µg_RAE
Magnesium	42 mg	Vitamin A	0 IU
Phosphorus	23 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	400 mg	Vitamin D	0 IU
Sodium	170 mg	Fatty acids, total saturated	0.011 g
Zinc	0.17 mg	Fatty acids, total monounsaturated	0.018 g
		Fatty acids, total polyunsaturated	0.041 g

quality after 8–14 days in contrast to those that were cooled as much as a day or two after harvest, which deteriorated quickly.

Postharvest physiology

Respiration rate was given in watts tonne⁻¹ as: 44–132 at 0 °C, 76–176 at 5 °C, 161–288 at 10 °C, 223–426 at 15 °C, 397–685 at 20 °C and 426–882 at 25 °C. Ethylene production and sensitivity were both reported to be low (SPLFS 2001).

Storage

At room temperature of 20 °C and 60% r.h. they could be kept for 2–3 days (Mercantilia 1989). However, Andre *et al.* (1980a) in five storage trials carried out on the cultivar, Violet de Provence showed that their storage life in air was 1 week at room temperature and 3–4 weeks at 1 °C. Fresh-cut chokes quickly turn brown, and Amodio *et al.* (2012) found that a 0.5% solution of cysteine was effective in preventing browning especially by increasing the natural pH from 2.1 to 3. The mean values of appearance scores for cysteine treated samples were all above the limit required for marketability and significantly higher than in control samples. Refrigerated storage recommendations were:

- 0–1 °C for 4 months (Wardlaw 1937).
- –0.5–0 °C and 85–95% r.h. for 1–3 weeks (Anonymous 1967).
- 0 °C and 95% r.h. for 15–20 days (Mercantilia 1989).
- 0 °C and 90–95% r.h. for at least 1 month (Hardenburg *et al.* 1990).
- 0 °C and 90–95% r.h. for 10–16 days (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 3–7 weeks (Snowdon 1991).
- 0 °C and 95–100% r.h. for 3–4 weeks (SPLFS 2001).
- 0 °C and 95–100% r.h. not exceed 2–3 weeks (Hygrotech SA 2004).

Controlled atmosphere storage

CO₂ concentrations of higher than 2% were reported to cause blackening of the chokes with a concomitant danger of decay (Miccolis and Saltveit 1988). However, storage recommendations were:

- 3% CO₂ with 3% O₂ in cold storage for 1 month to reduce browning (Pantastico 1975).
- 0–5 °C with 3–5% CO₂ and 2–3% O₂ which was said not to be used commercially (Kader 1985).
- 0–5 °C with 2–3% CO₂ and 2–3% O₂ which had only a slight effect (Saltveit 1989, Kader 1992).
- 0 °C and 90–95% r.h. with 3–5% CO₂ and 2–3% O₂ was recommended by SeaLand (1991).
- 0–1 °C and 95–100% r.h. with 2–3% CO₂ and 2–5% O₂ but it had no positive effect compared to storage in air (SPLFS 2001).

Modified atmosphere packaging

Storage in crates lined with perforated PE film was recommended by Lutz and Hardenburg (1968). Andre *et al.* (1980a) reported that at 1 °C their storage life was 3–4 weeks but this was extended to 2 months by a combination of vacuum cooling and packing in PE bags. Mencarelli (1987b) sealed chokes in films of differing permeability or perforated films for 35 days. Perforated heat sealed films gave poor results as did low permeability films but films sufficiently permeable to allow good gas exchange while maintaining high humidity gave good results with high turgidity and good flavour and appearance. Gil-Izquierdo *et al.* (2004) found that the cultivar

Blanca de Tudela stored at 5 °C had an equilibrium atmosphere of 14.4% O₂ + 5.2% CO₂ for those sealed in PVC bags and 7.7% O₂ + 9.8% CO₂ for those in LDPE bags. They showed that loss of water was the major cause of deterioration after 8 days of storage. However, the vitamin C content of the internal bracts (the edible part) decreased in MA packaging, while for those stored without packaging it remained at levels similar to those at harvest. There was also a high phenolic content (896 mg 100 g⁻¹ f.w.) in the internal bracts and this increased in those packed in LDPE and PVC but not in those stored without packaging. Alexopoulos *et al.* (2003) stored chokes at 2 ± 0.5 °C and 10 ± 1.0 °C in three types of MA packages for 28 days. The CO₂ concentration within the packages was 0.4–1.9% CO₂ at 2 °C, 1.9–3.2% at 10 °C for cling film (stretch PE film of 12 µ thick) and less than 0.4% at 2 °C and 0.1–1.1% at 10 °C for the other two films, which were 20 µm thick perforated PE film with 20 perforations 100 cm⁻² or 120 µm thick polystyrene film. Chokes that were not in plastic film lost 24–52% in weight at 2 °C and 48–51% at 10 °C after 2 weeks while those in plastic lost 2.5–5.5% at 2 °C and 5.4–11.1 at 10 °C after 4 weeks. Colour retention of the outer bracts was also improved in plastic film. Chokes in MA packaging and stored at 10 °C were only 20–40% acceptable after 2 weeks and zero after 28 days, while those stored at 2 °C had 60–100% acceptable after 28 days with cling film being slightly preferable to PE and polystyrene films. Hygrotech SA (2004) recommended cooling to below 5 °C as soon as possible after harvesting, preferably within 24 h, then sealing the chokes in 37.5 µm PE bags and storing them at –0.5 °C. With this combination of treatments they could be stored for 3 weeks and still have a shelf life of 5 days at 10 °C. They found that 50 µm bags or thicker resulted in the scale leaves becoming dark brown. They reported no serious quality problems with the marketing of artichokes after a voyage of 4 weeks from South Africa to Europe, provided they were well packaged.

Goa potato

Dioscoreaceae

Dioscorea aculeata L. is also called birch rind yam. Sturtevant (1892) wrote ‘Tropical Asia. This yam is

said to be a native of tropical, eastern Asia, and is cultivated in the Indian Archipelago, the Pacific Islands and the West Indies. The root is of a sweetish taste, and Dr Seemann regarded it as one of the finest esculent roots of the globe. It is cultivated in India and the tubers are dug, in the cold season, in the forests and sold in the bazaars. A variety cultivated at Caracas has a very delicious taste, though Lunan (1814), at Jamaica, says this yam is slightly bitter. This yam is said by Seemann, at Viti (a Fijian island), never to flower or fruit.'

Greater yam

Dioscoreaceae

Dioscorea alata L. is synonymous with *D. atropurpurea* Roxb., *D. colocasiifolia* Pax, *D. eburina* Lour., *D. eburnea* Lour., *D. globosa* Roxb., *D. javanica* Queva, *D. purpurea* Roxb., *D. sapinii* De Wild., *D. vulgaris* Miq., *Elephantodon eburnea* (Lour.) Salisb. and *Polynome alata* (L.) Salisb. The tuber flesh is white but some varieties have coloured flesh including *D. alata* var. *atropurpurea* and *D. alata* var. *rubella*. *D. rubella* Roxb. is also a synonym, and Sturtevant (1892) wrote of *D. rubella* 'East Indies. This is a common but very excellent yam of India, as good perhaps as any in cultivation. The tuber is of great size, crimson-red on the outside and of a glistening white within.' Other common names include white yam, purple yam, Guyana arrowroot, 10-months yam, water yam, winged yam, ratalu, violet yam, rasa valli kilangu, ube, ufi, khoai mō, Lisbon yam, Asiatic yam and greater Asiatic yam. Kay (1987) stated that *D. alata* is not known in the wild, but was developed from species originating in Southeast Asia and is now cultivated throughout the tropics. Burkill (1935) also stated that it is not known in the wild and either *D. hamiltonii* or *D. persimilis* may be an ancestor. Sturtevant (1892) wrote '*D. alata* Linn. white yam. Tropical Asia. This plant is cultivated in the tropics of the whole earth. Unger (Unger F. see U.S. Patent Office Reports) says the Indian Archipelago and the southern portions of the Indian continent is the starting point of this yam, thence it was carried first to the eastern coast of Africa, next to the west coast and thence to America, whence the names *yam* and *igname* are derived from the negroes. In the negro dialect of Guinea, the word yam means 'to eat'. This is the species most generally

cultivated in the Indian Archipelago, the small islands of the Pacific and the Indian continent. It is universally cultivated in the Carnatic region. There are several varieties in Jamaica, where it is called white yam.' Most varieties have wings on the stem with four ridges and no spines at the base of the plant, but in a few varieties the base of the stem has no wings and widely spaced spines. Tubers vary in size and flavour and they have a brown skin and commonly white flesh, but it can be pink or deep reddish-purple. Their shape may be cylindrical, globular, branched, lobed, flattened or fan shaped and normally weigh 5–10 kg, but can be as heavy as 60 kg (Coursey 1968, Kay 1987). In the town of Tunapuna in Trinidad and Tobago there is an annual yam festival and competition where enormous tubers are judged entirely on size; the biggest yam wins. Mr 'Pat' Coursey was a judge in 1969. Some cultivars of *D. alata* have aerial tubers that vary from zero to many.

Opara (1999) reported that the content of the edible part of *D. alata* per 100 g edible tuber was water 65–76 g, carbohydrate 20–31 g, fibre 0.6–1.5 g and protein 1.9–2.3 g. Knoth (1993) gave the following analysis on a fresh weight basis: 65–73% moisture, 22–29% carbohydrates, 0.1–0.3% fats and 1.1–2.8% crude protein. Shajeela *et al.* (2011) gave the following analysis on a fresh weight basis: starch 49.13 ± 0.21 g 100 g^{-1} , niacin 36.20 ± 0.24 mg 100 g^{-1} and ascorbic acid 74.56 ± 1.21 mg 100 g^{-1} . They also gave the following analysis for anti-nutritional factors: total free phenolics 0.68 ± 0.04 g 100 g^{-1} , tannins 0.41 ± 0.01 g 100 g^{-1} , hydrogen cyanide 0.17 ± 0.01 mg 100 g^{-1} , total oxalate 0.58 ± 0.03 g 100 g^{-1} , amylase inhibitor 6.21 AIU mg^{-1} and soluble starch trypsin inhibitor 3.65 ± 0.04 TIU mg^{-1} protein. In the apical and basal regions of the tuber, the starch content decreased while the sugars and α -amylase activity increased during storage (Muthukumarasamy and Panneerselvam 2000). Kay (1987) reported that a typical analysis of the edible portion of the tubers was water 65–73%, protein 1.12–2.78%, fat 0.03–0.27%, carbohydrate 22–29%, fibre 0.65–1.4% and ash 0.67–2.06%. She also reported that the starch from white-fleshed and purple-fleshed varieties had similar typical composition of moisture 13.6%, protein 0.14%, ash 0.22%, amylose 21.1%, reducing sugars 0.18%, pH 7.1 and an iodine value of 5.5. Ascorbic acid content ranged from 4.9 to 8.2 mg 100 g^{-1} of edible portion has been reported, while certain cultivars in the South Pacific

have been found to contain 6 mg 100 g⁻¹ of carotene. Three cyanidin glycosides have been isolated from *D. alata* var. *atropurpurea* and *D. alata* var. *rubella*. In Côte d'Ivoire Kouakou Dje *et al.* (2010) reported that tubers of *D. alata* and *D. cayenensis-rotundata* were stored for 6 months in a ventilated store where the conditions were 26.56 ± 3 °C and 82 ± 5% r.h. The total phenolic content varied in different parts of the tuber and decreased during storage. Protein content ranging from 7.90 to 7.94% and generally did not vary significantly during storage although a slight fall was observed in the distal part of one variety after 6 months. Lipids were low, only about 0.20% of the dry matter, and did not vary significantly during storage.

Harvesting

It normally matures 9–10 months after planting, but some varieties are harvested immature after some 6 months (Kay 1987). Harvesting is usually by digging the tubers by hand. Experimental mechanical harvesters were developed and tested in the University of the West Indies in Trinidad and Tobago by Dr Theo Ferguson and Dr Lewis Campbell. These were successfully used to harvest the tubers with minimum mechanical damage.

Curing

Gonzalez and de Rivera (1972) recommended 29–32 °C and 90–95% r.h. for about 4 days directly after harvest. Ravindran and Wanasundera (1993) successfully cured tubers by exposing them to sunlight for 3 days after harvest in mean ambient conditions of 29 °C and 84% r.h. Wilson (1980) described a simple method of curing *D. alata*. The tubers were first stacked on the ground in a lightly shaded area and covered with grass or mats. Then a canvas tarpaulin was placed over the whole stack to cover the grass or a mat ensuring the tarpaulin does not touch the yams. As an alternative, a simple wooden frame could be built and the canvas draped like a tent over the piled yams. She indicated that plastic sheets should not be used for curing since they can make the yams too hot. If no canvas tarpaulin was available she found that several layers of sacks or mats could be used.

Sprouting

The dormancy period for *D. alata* from the Caribbean or Nigeria was 14–16 weeks (Opara 1999, Passam 1982). Tubers of the cultivar Sree Keerthi and Sree Roopa, stored at room temperature of 30–32 °C and 80–85% r.h. in the dark sprouted 70–80 days after harvest (Muthukumarasamy and Panneerselvam 2000). Ravindran and Wanasundera (1993) found that sprouting started after 60–90 days in 24–28 °C and 70–90% r.h. A range of chemicals, which have been shown successfully to prevent sprouting in potato (*Solanum tuberosum*) tubers, were studied on yams but they all proved ineffective (Cooke *et al.* 1988). However, Passam (1982) showed that postharvest treatment of *D. alata* and *D. esculenta* with gibberellins could delay sprouting. Tschannen (2003) reported that gibberellic acid (GA₃) applied to *D. alata* directly after harvest prolonged dormancy and reduced respiration rate at the time of sprouting. Balogun *et al.* (2006) reported that applying GA₃ to the foliage prior to harvest had some effects. When applied to tubers soon after harvest GA₃ extended dormancy by 13 weeks (Gerardin *et al.* 1998). Tubers treated with GA₃ at the beginning of storage sprouted 4 weeks later than those not treated, the effect being less when treatments were given later and treatments given after 3 months of storage did not inhibit sprouting (Martin 1977).

Simple storage

Yams could be stored in ventilated barns at West African ambient conditions of about 30 °C and 60% r.h. for several months (Tindall 1983). In Nigeria yams are commonly stored in specially constructed barns. The design of these structures varies, but they usually consisted of live stakes driven into the ground and the tubers are suspended from these by twine. The live stakes produced foliage that shaded the tubers from the sun and provide a cool moist environment. In a comparison between barn storage and pit storage Ezeike (1985) recorded weight losses over a 5-month period of 60% for those in barn but only 15–25% for those in pits. Yams stored in slatted wooden trays in the coastal region of Cameroon had losses of 29–47% in only 2 months (Lyonga 1985). Tubers were stored for 150 days as thin layers on the floor of a well-ventilated room at room temperature of 24–28 °C and 70–90% r.h. Crude protein, starch

and ascorbic acid contents decreased significantly during the first 60 days of storage, but the decrease was gradual thereafter. Losses of some minerals and a significant reduction in levels of oxalates were also noted during storage (Ravindran and Wanasundera 1993).

Refrigerated storage

Storage at either 3 or 12 °C resulted in total physiological breakdown within 3–4 weeks (Czyhriniciu and Jaffe 1951). At 5 °C they appeared to store well for 6 weeks but on removal to 25 °C chilling injury symptoms occurred rapidly (Coursey 1961). Chilling injury symptoms included flesh browning and a susceptibility to microorganism infection. Opara (1999) reported that the optimum conditions for storage of *D. alata* were 15–17 °C and 70% r.h. for 180 days for cured tubers and 150 days for non-cured tubers. However, Opara (1999) differentiated between different *D. alata* varieties and reported that the optimum conditions for storage of Water Yam or Greater Yam was 30 °C for several months, and for White Yam or Guinea Yam it was 16 °C and 80% r.h. also for several months. Coursey (1961) recommended 12.5 °C for 8 weeks, and Gonzales and de Rivera (1972) and Opara (1999) recommended 15–17 °C and 70% r.h. for 180 days with about 11% weight loss for cured tubers and 150 days with about 12–25% weight loss for non-cured tubers.

Diseases

Postharvest rots of yams are common especially where they have been damaged during harvesting and handling. Snowdon (1990) described 15 microorganisms causing postharvest diseases in yams; mainly fungi. Ogali *et al.* (1991) treated tubers with either calcium oxide or local gin (fermented palm wine or sap from *Elaeis guineensis*) and then stored them at 25–32 °C with 62–90% r.h. for up to 32 weeks. After 24 weeks there was 25% rotting for those treated with gin and 5% for those treated with lime. After 32 weeks, the level of rotting was comparable in all treatments. Four species were isolated *Aspergillus niger*, *Fusarium oxysporum*, *Penicillium citrinum* and *Fusarium moniliforme* [*Gibberella fujikuroi*]; the first three species were found to be mildly pathogenic and the last species did not produce any rot symptoms.

Green beans

Fabaceae, Leguminosae

Phaseolus vulgaris L. Other common names include kidney beans, snap beans, green beans, common beans and French beans. They are native to the tropical areas of Central and South Americas and probably originated in the western parts of Guatemala and Mexico. They are widely grown in many areas around the world in both tropical and temperate conditions and are commonly used to prepare baked beans and in many Mexican recipes. See also runner bean *P. coccineus*. It is an annual climbing herb, whose edible portion is the pod or legume, which is long and slender containing up to 12 seeds. It is a polymorphic species and Kay (1979) divided them by use into:

- Dry shell or field beans
- Pea or navy beans
- Medium haricot beans
- Marrow beans
- Kidney beans
- Green shell haricot beans
- Horticultural haricot beans

The pods will freeze at about –1.3 to –1.1 °C (Wright 1942) or –0.89 to –0.72 °C (Weichmann 1987). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 67. Total world production in 2010 was estimated by FAO (2012) as 19,834,297 tonnes.

Postharvest physiology

Wills and Kim (1996) reported that green beans produce less than 0.05 µl kg^{–1} h^{–1} at 5 °C ethylene but exposure to amounts greater than 0.1 µl L^{–1} resulted in chlorophyll loss, increases browning and reduced storage life by 30–50% at 5 °C. Inaba *et al.* (1989) found that there was increased respiration rate in response to ethylene at 100 µl L^{–1} for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Respiration rates are given in Table 68.

Harvesting

This is when they are still young, crisp and tender and before there is any obvious swelling to show the beans are forming inside. It takes some 60–150 days from sowing to harvesting depending on cultivar and

Table 67 The composition of green beans for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	90.70 g	Thiamine	0.370 mg
Energy	29 kcal	Riboflavin	0.250 mg
Protein	4.20 g	Niacin	2.920 mg
Total lipid (fat)	0.50 g	Vitamin B-6	0.085 mg
Carbohydrate, by difference	4.10 g	Folate	59 µg_DFE
Calcium	17 mg	Vitamin B-12	0.00 µg
Iron	0.81 mg	Vitamin A	0 µg_RAE
Magnesium	21 mg	Vitamin A	2 IU
Phosphorus	37 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	187 mg	Vitamin D	0 IU
Sodium	6 mg	Fatty acids, total saturated	0.072 g
Zinc	0.40 mg	Fatty acids, total monounsaturated	0.039 g
Total ascorbic acid	38.7 mg	Fatty acids, total polyunsaturated	0.276 g

Table 68 Respiration rates of snap beans at different temperatures (source: adapted from Watada and Morris 1966)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	40
5	66
10	110
15	170
20	234

growing conditions. If harvesting is delayed they will become tough and stringy. Harvesting is by hand every 3–4 days.

Discolouration

Mechanical harvesting of green beans for processing may lead to discolouration of the broken ends of the beans, especially if there is a delay in processing them (Sistrunk *et al.* 1989). Exposing them to sulphur dioxide at 0.7% for 30 s reduced broken end discolouration as a result of mechanical injury (Henderson and Buescher 1977). Discolouration of the cut end can also be prevented by exposure to 20–30% CO₂ for 24 h (Hardenburg *et al.* 1990). Moisture condensing on the pods may cause a dark discolouration on the skin surface. This is a particular problem when they are removed from cold storage to warmer temperatures for marketing.

Pre-cooling

Forced air cooling with high humidity was the most acceptable method, but hydrocooling was said to be suitable and air cooling in a conventional cold store and vacuum cooling less suitable (MAFF n.d.). However, beans are highly susceptible to bacterial diseases and condensation spotting and therefore any pre-cooling that involves wetting the beans would normally be detrimental.

Storage

Chilling injury was reported to occur after 3–6 days at 4.4 °C (Anonymous 1968) or 3 days at 4.4 °C (Lutz and Hardenburg 1968). In both cases the symptoms did not occur until they were removed to a higher temperature. Guo *et al.* (2008) showed that the rate of respiration, which reached a peak rate of 109.2 CO₂ mg kg⁻¹ h⁻¹), weight loss, TSS and surface colour changes were lower during 12 days of storage at 0 °C compared to 8 or 25 °C. At room temperature of 20 °C and 60% r.h. they could be kept for about 2 days (Mercantilia 1989). Refrigerated storage recommendations are as follows:

- 4.4 °C and 85% r.h. (Platenius *et al.* 1934).
- 0–3.3 °C and 85% r.h. for 3 weeks with 20% loss (Wardlaw 1937).
- 2 °C and 90% r.h. for 2 weeks (Wardlaw 1937).
- 7.2 °C and 80–85% r.h. to 22 days (Wardlaw 1937).
- 7 °C for 5–8 days (Fidler 1963).
- 7.2 °C and 85–90% r.h. for 8–10 days if cooled immediately after harvest (Anonymous 1967).
- 7.2 °C and 90–95% r.h. for 1 week (Lutz and Hardenburg 1968).
- 4.4 °C and 90–95% r.h. for 10 days if they are processed immediately after storage (Lutz and Hardenburg 1968).
- 7.2–10 °C for 8–10, days 3.3–5.6 °C and 88% r.h. for 2–3 weeks with 18% loss (Pantastico 1975).
- 4–7 °C and high humidity with some variation in storage life between cultivars, but rarely longer than 10 days (Tindall 1983).
- 10 °C (Umiecka 1989).
- 5–6 °C and 90–95% r.h. (Mercantilia 1989).
- 0 °C for 2 days (Mercantilia 1989).
- 4 and 12 °C for 4 days (Mercantilia 1989).
- 5 °C for 7 days (Mercantilia 1989).
- 7.2 °C and 90–95% r.h. for 10–14 days (SeaLand 1991).

- 4.4 °C and 95% r.h. for 7–10 days for *haricot vert* (SeaLand 1991).
- 7–8 °C and 95–100% r.h. for 1–2 weeks (Snowdon 1991).

Controlled atmosphere storage

Kader (1985) reported that storage at 0–5 °C in 5–10% CO₂ + 2–3% O₂ had a fair effect but was of limited commercial use. Saltveit (1989) recommended 5–10 °C in 4–7% CO₂ + 2–3% O₂, which was said to have only a slight effect, but for those destined for processing 5–10 °C in 20–30% CO₂ + 8–10% O₂ was recommended. Storage in 5–10% CO₂ + 2–3% O₂ retarded yellowing; also discolouration of the cut end of the beans could be prevented from discolouration by exposure to 20–30% CO₂ for 24 h (Hardenburg *et al.* 1990). The same conditions were recommended by SeaLand (1991). High CO₂ levels could result in development of off-flavour, but storage at 7.2 °C in 5–10% CO₂ + 2–3% O₂ retarded yellowing (Anandaswamy and Iyengar 1961). Snap beans may be held for up to 3 weeks in 8–18% CO₂, depending on the temperature. CO₂ concentrations of 20% or greater always resulted in severe injury, as loss of tissue integrity followed by decay. At 1 °C, 8% CO₂ was the maximum level tolerated, while 18% CO₂ caused injury at 4 °C, but not at 8 °C. The cultivars Strike and Opus snap beans were stored for up to 21 days at 1, 4 or 8 °C in 2% O₂ + up to 40% CO₂, then transferred to air at 20 °C for up to 4 days (Costa *et al.* 1994). Sanchez-Mata *et al.* (2003) found that at 8 °C, 3% O₂ + 3% CO₂ was best in extending shelf life and preserved the nutritive value compared to storage in air, 5% O₂ + 3% CO₂, or 1% O₂ + 3% CO₂. Storage in 18% CO₂ at either 0 °C or 15 °C resulted in off-flavours and injury (Pantastico 1975). Sanchez-Mata *et al.* (2003) found that at 8 °C, 3% O₂ + 3% CO₂ was best in extending their storage life and preserved the nutritive value compared to storage in air, 5% O₂ + 3% CO₂ or 1% O₂ + 3% CO₂.

Hypobaric storage

Pods could be kept in good condition in storage for 30 days at reduced pressure compared to 10–13 days in cold storage alone (Haard and Salunkhe 1975). McCaslan 42 Pole Beans and Sprite bush beans stored better at 76 and 152 mm Hg at 7 °C for 2 weeks than

similar beans stored at 760 mm Hg (Spalding 1980). Burg (1975) found that beans stored at 7.2 °C and 60 mm Hg were in excellent condition after 26 days compared to those stored at the same temperature at 760 mm Hg that were shrivelled and in poor condition.

Hypobaric storage has been shown to be effective on dried beans. Berrios *et al.* (1999) reported that the combined effect of refrigeration and hypobaric storage demonstrated potential for maintaining the fresh quality of black beans (*P. vulgaris*) in storage for up to 2 years. Black beans stored at 4.5 °C and 50–60% r.h. and atmospheric pressure of 125 mm Hg exhibited quality factors characteristic of fresh beans, such as shorter cooking time, smaller quantities of solids loss, electrolytes leached and percentage of hard-shell than beans stored at 23–25 °C and 30–50% r.h. At 4.5 °C, beans stored in 125 mm Hg had a germination rate of 93% while those stored at atmospheric pressure had 72%. Beans stored in ambient conditions exhibited hard-to-cook.

Modified atmosphere packaging

The quality of 15 cultivars of French beans stored in LDPE at 8–10 °C was acceptable for up to 30 days, after which the colour changed to light brown in some of the cultivars. At that time the cultivar CH-913 had the highest percentage of beans that were still considered marketable which was 92.55% (Attri and Swaroop 2005).

Hoi

Dioscoreaceae

Dioscorea sativa L. *D. sativa* var. *rotunda* F.M. Bailey synonymous with *D. bulbifera* L. Coursey (1967) stated that none of the uses of the name *D. sativa* is valid and the use of this taxon in any context should be abandoned. He stated *D. sativa* is often applied incorrectly to *D. sativa* Thum., which is a synonym of *D. bulbifera* L. *D. sativa* Del. is applied to certain Indian varieties of *D. alata* and *D. sativa* Beatson is synonymous with *D. cayenensis*. It is a vine with minute flowers growing on a gracefully pendulous stem up to 40 cm in length, which, together with the large dark green leaves and peculiar tuber give the plant a unique appearance. The tubers are

up to 8 cm in diameter produced at the node of the stem, simultaneously with minute flowers on a pendulous stem 25–37 cm long. Tubers have a very bitter taste and were only used as a famine food. ‘Tropics. Pickering states that this species is found in tropical America and is cultivated by the Waraus of the delta of the Orinoco. The word *igname* was heard by Vespucius on the coast of Para and was found by Cabral, in 1500, applied in Brazil to a root from which bread was made. This yam was carried by European colonists to the Malayan Archipelago. Its roots, says Seemann, are acrid and require to be soaked before boiling. Browne says it is cultivated in the southern United States for its large, flattened and sometimes palmated roots, which are boiled, roasted and eaten like the potato’ (Sturtevant 1892).

Horseradish

Cruciferae

Armoracia rusticana Gaertn., Mey. et Scherb. It originated in the southern part of Russia and the eastern part of the Ukraine (Tucker and DeBaggio 2009). *A. rusticana* is one of three *Armoracia* spp. *A. rusticana* is putatively native to Eastern Europe, *A. macrocarpa* is native to the Central Danube River Basin and *A. sisymbrioides* is native of Siberia. It has been cultivated for its root for over 2000 years for its culinary and medicinal benefits (Sampliner and Miller 2009). During the Renaissance, horseradish consumption spread from Central Europe northward to Scandinavia and westward to Britain. It was not until 1640 that the British ate horseradish. By the late 17th century, horseradish was the standard accompaniment for beef and oysters among the English. It was also grown at inns and coach stations to make cordials to revive exhausted travellers. Early settlers took horseradish to North America and began cultivating it in the colonies and it was reported to be growing wild near Boston by 1840 (Murray and Pizzorno n.d.). In the United States production area was about 1500 acres mainly in the Mississippi River Valley region, which has been producing horseradish commercially for over 150 years (Courter and Rhodes 1969, Walters and Wahle 2010). Ancient Greeks and Romans cultivated horseradish for medicinal uses such as back pain and menstrual cramps.

Research has shown that horseradish protected against *Listeria*, *Escherichia coli*, *Staphylococcus aureus* and other food pathogens (Murray and Pizzorno n.d.) because it contains mustard oil, allyl isothiocyanate, one of the pungent chemicals formed when horseradish is cut. It is also responsible for the pungent taste of horseradish as well as that of mustard (*Brassica juncea*) and wasabi (*Wasabia japonica*). This powerful antibacterial ingredient constitutes 60% of horseradish oil.

A. rusticana is propagated vegetatively and is not found in the wild. *A. macrocarpa* and *A. sisymbrioides* are reproduced by seed in the wild (Sampliner and Miller 2009). It is a herbaceous plant that produces long cylindrical fleshy roots whose white flesh has a very pungent flavour. It is a very persistent plant ‘once a horseradish grower, always a horseradish grower’.

Weichmann (1987) reported an average water content of fleshy roots was 75% and their highest freezing point was 1.8 °C or about –3.8 to –2.4 °C (Wright 1942). They have high levels of vitamin C that decreases during storage especially in roots that are harvested early. Mustard oils are usually bound in the vacuoles of the plant cells with sugars as either allyl glucosinolate or β -phenylethyl glucosinolate. They are separated from the membrane-bound enzyme myrosinase and this barrier that separates the plant vacuoles from the myrosinase is broken down when the skin of the horseradish root is ruptured. This results in the hydrolysis of the sugar bonds by the myrosinase, which in turn releases the isothiocyanates (Tucker and DeBaggio 2009). The reaction only occurs if the skin is ruptured and its effects are short-lived. The essential oil of horseradish is toxic and should be treated with extreme caution, but cooking destroys the toxicity of the chemical. An ether extract of a ground root had 76–80% allyl isothiocyanate and 16–18% β -phenylethyl isothiocyanate (Van Wyk and Wink 2004).

Harvesting

In temperate countries the roots are harvested when the tops have been killed by frost, they store very well. Immature roots or those that are actively growing do not store well (Kay 1987, Lutz and Hardenburg 1968). If the roots cannot be harvested before the ground freezes, they can be left to overwinter and then dug up in the spring before the plant is actively growing.

To prepare for harvesting the soil should be loosened around the roots to minimize breakage of the side shoots. A spade can be used to undercut the root system and lift the plant out of the ground, taking care to not leave any remnants of the root behind. Once the main root is removed from the ground the side shoots should be taken off. Small, thin roots can be saved for planting. If the plant is being grown as a perennial, it should be replanted immediately after the roots have been harvested (Tucker and DeBaggio 2009). For mechanized harvesting the tops are cut off then a converted potato diggers, or other equipment, is used to undercut the roots and remove the plant from the soil.

Postharvest physiology

The respiration rate of the fleshy roots in storage was given as in $\text{mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ as 8 at 0°C , 14 at 5°C , 25 at 10°C and 32 at 20°C . Ethylene production was less than $1 \mu\text{l kg}^{-1} \text{ h}^{-1}$ (Gross *et al.* 2002).

Storage

They may be stored over winter in cellars, pits or trenches. At room temperature of 20°C and 60% r.h. it was claimed that they could be kept for only 7–10 days (Mercantilia 1989). Adamicki *et al.* 1999 also reported that pungency is rapidly lost during storage at higher temperatures. Whole roots can be buried in a layer of moist sand or placed in ventilated plastic bags in a refrigerator and stored for up to 3 months (Tucker and DeBaggio 2009). Refrigerated storage recommendations include:

- -1.1 to 0°C and saturated atmosphere for up to 1 year (Hoyle 1956).
- -1.1 to 0°C and 90–95% r.h. for 10–12 months (Lutz and Hardenburg 1968).
- -1 to 0°C and 95% r.h. for 10–12 months (Mercantilia 1989).
- 0°C and 95–100% r.h. for 300–350 days (SeaLand 1991).
- 0°C with 98–100% r.h. for 8–12 months (Adamicki *et al.* 1999).

Controlled atmosphere storage

Controlled atmosphere storage was reported to have had only a slight to no effect (SeaLand 1991) and

was not recommended by Saltveit (1989). It is not necessary since they store well in refrigerated storage in air. Weichmann (1981) studied different levels of CO_2 of up to 7.5% during 6 months of storage at 0 – 1°C and found no detrimental effects of CO_2 but no advantages over storage in air. He did, however, find that those stored in 7.5% CO_2 had a higher respiration rate and higher total sugar content than those stored in air. Gui *et al.* (2006) reported that exposure to high levels of CO_2 could result in some reduction in enzyme activity but activity returned to what it was when they were removed and stored in air.

Modified atmosphere packaging

Hoyle (1956) commented that storage in containers lined with perforated film was advantageous since it provided a high humidity and suggested prepacking them in perforated plastic bags for marketing. Adamicki *et al.* 1999 reported that roots dry out in lower humidity and storage in perforated PE bags and lined crates or bins can maintain a high humidity during storage.

Diseases

Penicillium root rot (*Penicillium hirsutum*) and Rhizoctonia root rot (*Rhizoctonia solani*) have been reported infecting roots. The symptoms of Penicillium root rot are greenish-blue mass of spores on the surface, which appeared more common on roots stored in pits rather than in cold storage. Infection with Rhizoctonia root rot gave the roots a light yellow to greyish tan colour and creamy white mycelia on the surface eventually dotted with brownish black sclerotic. The disease was retarded in storage at -1.1 to 0°C (Ryall and Lipton 1979).

Indian arrowroot

Zingiberaceae

Curcuma spp. Roxb. also called East Indian arrowroot. The genus *Curcuma* contains about 70 species of rhizomatous herbs distributed in India, Cambodia, the Malaysian Archipelago and northern Australia. Some 30 species occur in India where *C. angustifolia* Roxb. (East Indian arrowroot) occurs in the hilly tracts of Bengal, Maharashtra, Tamil Nadu and some

of the lower Himalayan ranges. The plant grows in the wild in many places and is found in moist and cool habitats up to an altitude of 500 m (Kundu 1967).

Curcuma spp. are herbs that grow up to 1 m high and have green leaves with brownish-purple veins on either side of the midrib. The base of each erect stem has an oval-shaped primary tuber which develops many branched curved rhizomes as they mature. The rhizomes are large, fleshy, branched and their flesh is pale yellowish-brown in colour. Starch is extracted from *C. angustifolia* and used in a similar way to that of arrowroot (*Maranta arundinacea*) (Purseglove 1972). Several species including *C. aromatica*, *C. harita*, *C. malabarica* and *C. zedoaria* are used for extraction of starch having medicinal applications (Kundu 1967). The major constituents in the rhizome oil from central India were xanthorrhizol isomer 12.7%, methyl eugenol 10.5%, palmitic acid 5.2% and camphor 4.2%, while the rhizomes oil from Travancore, southern India had germacrone 12.8%, camphor 12.3%, isoborneol 8.7%, curdione 8.4% and 1,8-cineole 4.8% as major constituents (Srivastava *et al.* 2006).

Indian spinach

Basellaceae

Basella alba L. synonymous with *B. rubra* L. Other common names include vine spinach and basella. It probably originated in Asia but is cultivated throughout the tropics for its young tender leaves and stems that are used as spinach. It is a perennial twining glabrous herb with small whitish flowers in axillary spikes. Leaves are fleshy and up to 15 cm long (Purseglove 1972). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 69. Harvesting is when the leaves are still young and tender, which is some 80–90 days after sowing.

Indian yam

Dioscoreaceae

Dioscorea triloba Lam. is synonymous with *D. trifida* Linn., which was reported to have originated in Guiana and Central America. This species is cultivated for its edible tubers. Sturtevant (1892) wrote 'Guiana. This is the smallest and most delicate of the

Table 69 The composition of Indian spinach for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.10 g	Total ascorbic acid	102.0 mg
Energy	19 kcal	Thiamine	0.050 mg
Protein	1.80 g	Riboflavin	0.155 mg
Total lipid (fat)	0.30 g	Niacin	0.500 mg
Carbohydrate, by difference	3.40 g	Vitamin B-6	0.240 mg
Calcium	109 mg	Folate	140 µg_DFE
Iron	1.20 mg	Vitamin B-12	0.00 µg
Magnesium	65 mg	Vitamin A	400 µg_RAE
Phosphorus	52 mg	Vitamin	8000 IU
Potassium	510 mg	Vitamin D (D2 + D3)	0.0 µg
Sodium	24 mg	Vitamin D	0 IU
Zinc	0.43 mg		

yams grown in Jamaica. It seldom exceeds eight or nine inches in length and two or three in diameter and is generally smaller. The roots have a pleasant, sweetish taste, very agreeable to most palates.'

Intoxicating yam

Dioscoreaceae

Dioscorea hispida Dennst. It is synonymous with *D. daemona* Roxb., *D. hirsuta* Blume, *D. lunata* Roth., *D. mollissima* Blume, *Helmia daemona* (Roxb.) Kunth and *H. hirsuta* (Blume) Kunth. Other common names include Asiatic bitter yam, karukandu, gadoeng, gadong mabok, killoi, koi, maranpash poll, mo, palidumpa and pashpoli. *D. hispida* originated in Southeast Asia and grows wild in India, Indonesia, the Philippines, South Western China, Formosa, Malaya and Papua New Guinea. They thrive in tropical rain forest conditions (Kay 1987) and occur from sea level in the Philippines and up to 1200 m in the Himalayas. It grows wild in Java, where it is called gadoeng. Sturtevant (1892) wrote 'In 1894 W. G. Boorsma (*Mededeelingen wuit's Lands Plantentuin*, xiii) separated from it an alkaloid to which he gave the name of *dioscorine*. This alkaloid has been studied by Plugge and Schutte (*A.J.P.*, iv, 1897) who assigned to it the formula C₁₃H₁₉NO₂ and found it to be a convulsant poison, resembling closely in its action picrotoxin, but much more feeble.' They were reported to be a major famine food, but the tubers were also reported to have been used in criminal poisoning and also as an ingredient, together with *Antiaris toxicaria*,

in the preparation of arrow poisons. *A. toxicaria* is a tree of the Moraceae family grown in Java and its neighbouring islands (Kay 1987).

D. hispida is a climbing plant usually with a prickly stem. The leaves are trifoliate with ovate to obovate leaflets, about 10 cm long and 8 cm broad, hairy, with small prickles on abaxial side. Male flowers are in large, branched inflorescences and the female inflorescences are unbranched. Several globose to deeply lobed tubers are borne on each plant, which may be fused into a cluster weighing up to 35 kg. Tubers are pale skinned and covered with masses of fibrous roots (Kay 1987).

Kay (1987) gave an approximate analysis of the tubers as: water 78%, carbohydrate 18%, protein 1.81%, fat 0.16%, fibre 0.93% and ash 0.69% on a fresh weight basis. On a dry weight basis the tubers contained 0.2–0.7% diosgenin and 0.044% dioscorine. The tuber is a rich source of starch and is a good source of phosphorus, calcium and iron. They are extremely poisonous owing to presence of alkaloids of the dioscorine group. Consumption of these without careful preparation can be fatal. Traditionally, the toxicity is overcome by soaking the sliced or grated tubers so that the alkaloid leaches out into the water (Lancaster and Coursey 1984). Dioscorine can also be removed by slicing or grating, boiling them or covering them in wood ashes and finally placing them in running water or repeated changes of salt water (Kay 1987). Sulit (1967) describes a technique used in the Philippines where thin slices of peeled tubers were placed in a basket and submerged in the sea or a solution of salt water for 2–3 h. They were then removed and squeezed under weights for a few hours and then replaced in the baskets and left in a running stream for 36–48 h with occasional stirring. The slices were tested for toxicity by squeezing a drop of liquid into the eye and if the eye smarted, soaking was continued for a further period. It is a matter of concern that drops of the extract are placed in the eye.

The tubers are mature some 12 months after planting. Harvesting is usually easy since tubers may be produced just below the soil surface and are harvested by digging by hand. The tubers may be collected throughout the year therefore storage is not necessary. However, they can also be stored buried in moist sand (Kay 1987).

Japanese yam

Dioscoreaceae

Dioscorea japonica Thunb. Coursey (1967) stated that it is considered by some authorities to be a form of *D. opposita*. Other common names include Chinese yam, pinyin, shan yao and Taiwanese yam. It is a native of Japan and is widely cultivated as a food crop in Japan, China and neighbouring islands (Coursey 1967). Burkill (1935) stated that the dried tuber is cut into shavings and used in Chinese medicine and as a tonic. Sturtevant (1892) wrote 'The roots, cut into slices and boiled, have a very pleasant taste.' They are used as a medicine known as San Yak in Korea. Kim *et al.* (2011) isolated dioscorolide A and dioscorolide B from the tubers and showed cytotoxicity against tumour cell lines and suggested that there may be selective toxicity among tumour and normal cells.

Jerusalem artichoke

Compositae

Helianthus tuberosus L. Other common names include girasole, sunroot and topinambour. It is a native of North America and was cultivated by the Native Americans in the north-eastern part of the continent in pre-Columbian times. It was introduced into Europe in the early 17th century and is now widely grown in both hemispheres (Kay 1987). It is interesting because of its high sugar content, primarily inulin, productivity and possibilities of cultivation on marginal land (Daničenko *et al.* 2008).

An erect, hardy tuberous perennial up to 1.2 m high when grown in the tropics and up to 3 m in more temperate areas. The lower leaves are opposite and the upper alternate and are finely pubescent on abaxial side. The flowers have yellow florets and are about 6–7.5 cm in diameter. The plant produces a number of tubers up to 8 cm in diameter and up to 20 cm long. They have large pronounced eyes and a thin white, or sometimes red, skin with white flesh (Harrison *et al.* 1985). The tubers contain high levels of inulin, which has been considered to be a bulking agent for artificial sweeteners (McLaurin *et al.* 1999). Tubers contained 20.4–31.9% of dry matter, from which carbohydrates were the main components. Most of the carbohydrate consisted of water-soluble inulin. Concentration of inulin

Table 70 The composition of Jerusalem artichokes for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	78.01 g	Thiamine	0.200 mg
Energy	73 kcal	Riboflavin	0.060 mg
Protein	2.00 g	Niacin	1.300 mg
Total lipid (fat)	0.01 g	Vitamin B-6	0.077 mg
Carbohydrate, by difference	17.44 g	Folate	13 µg_DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Sugars, total	9.60 g	Vitamin A	1 µg_RAE
Calcium	14 mg	Vitamin A	20 IU
Iron	3.40 mg	Vitamin E (α-tocopherol)	0.19 mg
Magnesium	17 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	78 mg	Vitamin D	0 IU
Potassium	429 mg	Vitamin K (phylloquinone)	0.1 µg
Sodium	4 mg	Fatty acids, total saturated	0.000 g
Zinc	0.12 mg	Fatty acids, total monounsaturated	0.004 g
Total ascorbic acid	4.0 mg	Fatty acids, total polyunsaturated	0.001 g

was 50–56% of dry matter or 11.3–14.2 g 100 g⁻¹ f.w. of tubers. Soluble carbohydrates, besides inulin, are its derivatives fructo-oligosaccharides, fructose, glucose and sucrose (Danilčenko *et al.* 2008). Shaufer *et al.* (1972) gave the following sugar content for fresh tubers of the cultivar Manitoba: reducing sugar 20.6%, fructose 79.7% and glucose 12.7% on a d.w. basis. For the cultivar Russian they gave reducing sugar 16.9%, fructose 76.8% and glucose 13.5%. They also reported that at harvest dry matter was 25.8% and total reducing sugar 78.4%, but after 8 weeks of storage at 3 °C and 95% r.h. the dry matter was 25.5% and total reducing sugar 66.7%. After 8 weeks at 3 °C and 75% r.h. dry matter was 28.2% and the total reducing sugar 62.9%. Beside soluble carbohydrates, tubers contain the dietary fibres, cellulose, lignin, pectins and hemicelluloses (Danilčenko *et al.* 2008). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 70.

Harvesting

Harvesting can be carried out when the leaves begin to wither. In Britain they are commonly harvested in autumn but harvesting can be delayed until spring

since they keep well buried in the soil. Tubers have a thin, easily damaged surface that can allow rapid water loss (Saengthobpinit and Sajjaanantakul 2005).

Postharvest physiology

Tubers are not sensitive to ethylene. Respiration rate was affected by temperature as follows: at 0 °C it was 10.2 mg CO₂ kg⁻¹ h⁻¹, at 5 °C it was 12.3 mg CO₂ kg⁻¹ h⁻¹, at 10 °C it was 19.4 mg CO₂ kg⁻¹ h⁻¹ and at 20 °C it was 49.5 mg CO₂ kg⁻¹ h⁻¹ (Kays 1997). Gross *et al.* (2002) reported similar respiration rates as 10 at 0 °C, 12 at 5 °C, 19 at 10 °C and 50 mg CO₂ kg⁻¹ h⁻¹ at 15 °C.

Storage

High storage losses can be attributed to the fact that tubers lack of a corky surface layer, similar to that found on potatoes, sweetpotatoes, yams etc., which could reduce transpiration (Saengthobpinit and Sajjaanantakul 2005). Therefore storage at high humidity is essential to reduce water loss. Danilčenko *et al.* (2008) also reported that storage of harvested tubers usually results in high losses in quality, caused mainly owing to desiccation, rotting, sprouting, freezing and inulin degradation. In Eastern Europe simple store houses are used or over-wintering tubers in an open field but this can result in some freezing injuries. Storing tubers in the soil can result in difficulties of harvesting tubers from the soil during winter so sandy, well-drained soils are preferred because they allow harvesting throughout the winter (Danilčenko *et al.* 2008). Volk and Richards (2006) stored tubers of nine cultivars and found that most of them could be maintained at 5 °C or under 25 °C in growth room conditions for at least 6 months. Kays (1997) reported that freezing temperatures of –10 °C, whether in the field or storage, caused rapid deterioration, but non-lethal freezing at –5 °C caused little damage. Tubers will freeze at about –2.7 to –2.3 °C (Wright 1942). As with most fleshy plant products, temperature at which freezing damage occurs and the extent of damage varies with cultivar, season, preconditioning, rate of freezing and other factors. Some cultivars are much more susceptible to storage losses than others (Steinbauer 1932). Tubers shrivel readily at low humidity and are more likely to decay. At room temperature of 20 °C and 60% r.h. they could be kept for

1–2 weeks (Mercantilia 1989). At temperatures over 4 °C they lost moisture rapidly and shrivelled, while at 16 °C in still air they developed mould growth in 2–3 weeks (Wardlaw 1937). At low humidity they shrivel badly and were more likely to decay than if kept in a moist atmosphere. Their thin skin is easily injured and allows moisture to be lost readily, causing shrivelling. If stored for 5 months, losses due to decay and shrivel may amount to 20% (Hardenburg *et al.* 1990). Refrigerated storage recommendations include:

- 0–2 °C and 90–95% r.h. for 6–12 months (Steinbauer 1932).
- 0–1.7 °C and 89–92% r.h. for 4 months (Wardlaw 1937).
- 0 °C and 90–95% r.h. for 150 days with 20% loss due to decay and shrivelling (Tindall 1983).
- –0.5 to 0 °C and 90–95% r.h. for 2–5 months (Anonymous 1967, Hardenburg *et al.* 1990).
- 0 °C and 90% r.h. for 3–5 month (Mercantilia 1989).
- 0 °C and 90–95% r.h. for 100–150 days (SeaLand 1991).
- –0.5 to 0 °C and 90–95% r.h. for 2–5 months (Snowdon 1991).
- 0–1 °C 95–98 r.h. for 6 months (Cantwell 2001).
- 0–2 °C and 90–95% r.h. for several months (Danilčenko *et al.* 2008).

Controlled atmosphere storage

Depending on cultivar, tubers can be stored for up to 12 months at 0–2 °C and 90–95% r.h. therefore there is little justification for using controlled atmosphere storage (Steinbauer 1932). However, Denny *et al.* (1944) reported that storage in 22.5% CO₂ + 20% O₂ significantly retarded the rate of inulin degradation, apparently through an effect on enzyme activity.

Packaging

In storage experiments with the cultivar Swojecki, tubers were kept at 2 °C and 90–95% r.h. for 4 months in polypropylene net bags or buried in sand or peat. The biggest weight loss after 2 months was for tubers kept in polypropylene net bags, while those in sand or peat had significantly less weight loss. The tubers in polypropylene net bags had the highest loss of

soluble solids (4%) after 4 months. The lowest content of total sugars and sucrose in tubers was found after 2 months of storage in all the packaging treatments, but the highest concentration of reducing sugars was found in tubers stored in polypropylene net bags (Danilčenko *et al.* 2008).

Diseases

Approximately 20 organisms causing storage rots have been isolated from Jerusalem artichoke tubers. The organisms most frequently isolated were *Botrytis cinerea* and *Rhizopus stolonifer*, though *R. stolonifer* and *Sclerotinia sclerotiorum* were reported to be the most serious organisms causing rots at low storage temperatures. *Sclerotium rolfsii* and *Erwinia carotovora* were not significant pathogens at temperatures below 20 °C. Postharvest rots were controlled by storage at 0–2 °C, removal of diseased tubers, minimizing mechanical damage and control of humidity (Kays 1997).

Kaede dokoro

Dioscoreaceae

Dioscorea quinqueloba Thunberg. Sturtevant (1892) wrote 'Japan. This species is an edible yam of Japan.' It grows in Honshu, west of the central region, Shikoku, Kyushu, Okinawa as well as Korea and China in the mountains and forest edge. It is used widely in traditional medical practice. In Korea Kim *et al.* (2011) reported that they encountered cases of acute renal failure associated with ingestion of *D. quinqueloba*. They emphasized that this tuber should be correctly prepared for traditional medicine, otherwise it may cause a life-threatening acute kidney injury.

It is a tuberous vine whose leaves are 6–12 cm long and 4–10 cm wide. The flowers are pale yellow and are produced in July to September with fruits that are up to 16 mm long.

Kale

Brassicaceae, Cruciferae

Brassica oleracea L. var. *acephala* DC. are called kale, borecole, sprouts or winter greens, while *B. oleracea* var. *acephala* f. *viridis*, *B. oleracea* L., and

B. oleracea var. *sabellica* are usually called collards. Some authorities differentiate between *B. oleracea* var. *acephala* f. *sabellica* L. called borecole or kale and *B. oleracea* var. *acephala* f. *viridis* DC. called collards. Synonyms include *B. alboglabra* Bailey, *B. oleracea* var. *alboglabra* (Bailey) Sun., *B. oleracea* var. *albiflora* O. Kunze, *B. oleracea* var. *acephala* f. *viridis* DC., *B. oleracea* var. *viridis* L., and *B. oleracea* var. *acephala* f. *sabellica* L. Residual populations of wild kale are reported to still occur in the Crimea, which have been identified as *B. rupestris-incana*. In the wild, the *B. oleracea* plant is native to the Mediterranean region of Europe where kale developed and became adapted to most of the world's temperate zones and even parts of the sub-arctic and tropical zones (Boyette *et al.* n.d.). By the 5th century BCE preference for ever-larger leaved *B. oleracea* plants led to the development of kale. It has been cultivated for over 2000 years and in much of Europe it was the most widely eaten green vegetable until the Middle Ages when cabbages became more popular. Historically it has been particularly important in colder regions owing to its resistance to frost. Kale was grown as a staple crop in the Scottish islands owing to its extreme hardiness and was given protection from the elements in purpose built kale yards. Kale continued to be extremely important until the end of the 18th century when potatoes were introduced (Anonymous n.d. Collards). Kale is grown in Europe for animal feed, but there are varieties that are grown as a vegetable for human consumption. They are erect branched herbs and form a rosette of smooth leaves at the apex of the stem.

Raw kale has nearly four times as much vitamin C as an equal weight of oranges or limes (Boyette *et al.* n.d.). Watada (1987) reported that collards had 152 mg vitamin C, 0.16 mg thiamine, 0.31 mg 100 g⁻¹ riboflavin and 9300 IU vitamin A. He also reported that losses of vitamin C after 4 days of storage were 2% at 0 °C, 30% at 10 °C and 58% at 21 °C. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 71.

Harvesting

Markle *et al.* (1998) reported that from sowing to harvest took 2–3 months with harvesting while the leaves are still young and tender. Peirce (1987) reported the practices in the United States where

Table 71 The composition of kale/collards for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Collards	Kale
Water (g)	90.55	84.46
Energy (kcal)	30	50
Protein (g)	2.45	3.30
Total lipid (fat) (g)	0.42	0.70
Carbohydrate, by difference (g)	5.69	10.01
Total dietary fibre (g)	3.6	2.0
Sugars, total (g)	0.46	–
Calcium (mg)	145	135
Iron (mg)	0.19	1.70
Magnesium (mg)	9	34
Phosphorus (mg)	10	56
Potassium (mg)	169	447
Sodium (mg)	20	43
Zinc (mg)	0.13	0.44
Total ascorbic acid (mg)	35.3	120.0
Thiamine (mg)	0.054	0.110
Riboflavin (mg)	0.130	0.130
Niacin (mg)	0.742	1.000
Vitamin B-6 (mg)	0.165	0.271
Folate (µg_DFE)	166	29
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	333	769
Vitamin A (IU)	6,668	15,376
Vitamin E (α-tocopherol) (mg)	2.26	–
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phyloquinone) (µg)	510.8	817.0
Fatty acids, total saturated (g)	0.055	0.091
Fatty acids, total monounsaturated (g)	0.030	0.052
Fatty acids, total polyunsaturated (g)	0.201	0.338

individual leaves are removed and the rest of the plant is left to continue growing. The leaves are washed and tied into bunches in the field. They are packed with one or two dozen bunches per waxed cardboard carton and hydrocooled in the cartons. Collards can be harvested as leaf-collards, in which case only leaves of the proper size and maturity are harvested, or as head-collards, in which case the entire plant is taken. Collards intended for machine harvesting are normally planted very close together and harvested at the four to eight leaf stage (Boyette *et al.* n.d.).

Curing

Collards cured in moist air at 40 °C and high humidity for 60 min maintained their leaf structure and had delayed onset of yellowing during subsequent storage, compared to untreated and other heat treatments.

When temperature and duration exceeded tolerance levels, heat injury was observed. In some cases of heat injury, tissues maintained their green colour but developed fungal infection (Wang 2000).

Storage

Storage recommendations were 0 °C and 90–95% r.h. for 10–14 days (Peirce 1987, SeaLand 1991). Hagen *et al.* (2009) found that storage of curly kale at 1 °C for 6 weeks had no effect on the antioxidant capacity, total phenols or flavonol content, but the content of vitamin C and sugars was reduced. In plants that remained in the field for 6 additional weeks, including many days with frost, the levels of flavonols, total phenols and antioxidant capacity were reduced by 25–35% and the vitamin C content by more than 50%, whereas TSS increased by about 20% and dry matter by about 30%.

Diseases

Operations that involved extended storage periods and mechanical handling tended to increase total plate counts of the members of Enterobacteriaceae, yeasts and moulds. The members of Enterobacteriaceae isolated from the frozen product were those commonly associated with soil contamination and not normally considered pathogenic to humans (Senter *et al.* 1987).

Kasha kanda

Dioscoreaceae

Dioscorea puber Bl. Enum. Other common names include kukai sanga, kosa alu and chekka alu. A large species widely distributed in India and Malaysia (Coursey 1967). It is a pubescent climber that produces bulbils in the leaf axils that are eaten as vegetables. In Odisha, India both bulbils and tubers are used as vegetables mainly during the times when other staples are in short supply (Kumar *et al.* 2012). Coursey (1967) reported that the tubers have an unpleasant smell and are therefore only used in times of famine. Tubers are cylindrical and up to 90 cm long and 30–38 cm wide growing downwards with brown hairy skin and light yellow flesh.



Figure 36 Kohlrabi on sale in a green grocer's shop in the United Kingdom in 2013. See colour plate section.

Kohlrabi

Brassicaceae, Cruciferae

Brassica oleracea var. *gongylodes* L. or *B. oleracea* L. Gongylodes group. It is also called turnip rooted cabbage. In the wild, the *B. oleracea* plant is native to the Mediterranean region of Europe. Kohlrabi was first reported in the Middle Ages in central and southern Europe and became well established in Asia some 200 years ago where it remains an important crop.

The edible portion is the spherical secondary thickened stem that is up to 10 cm in diameter. It bears leaves just like a normal stem, and it commonly has green or purple skin with white flesh (Figure 36). It will freeze at about –1.3 to –1.0 °C (Wright 1942). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 72.

Harvesting

If over mature they can be tough and fibrous so they should be harvested when they are of an acceptable size and the leaves still appearing fresh and healthy. Tindall (1983) found that they normally mature within 10 weeks from transplanting and should be harvested before they become fibrous and woody. Hand-harvesting direct into nets or boxes or mechanized harvesting using a rig washing and packing machine is used in the United Kingdom (Red Tractor 2008).

Table 72 The composition of kohlrabi for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	91.00 g	Thiamine	0.050 mg
Energy	27 kcal	Riboflavin	0.020 mg
Protein	1.70 g	Niacin	0.400 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.150 mg
Carbohydrate, by difference	6.20 g	Folate	16 µg_DFE
Total dietary fibre	3.6 g	Vitamin B-12	0.00 µg
Sugars, total	2.60 g	Vitamin A	2 µg_RAE
Calcium	24 mg	Vitamin A	36 IU
Iron	0.40 mg	Vitamin E (α-tocopherol)	0.48 mg
Magnesium	19 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	46 mg	Vitamin D	0 IU
Potassium	350 mg	Vitamin K (phylloquinone)	0.1 µg
Sodium	20 mg	Fatty acids, total saturated	0.013 g
Zinc	0.03 mg	Fatty acids, total monounsaturated	0.007 g
Total ascorbic acid	62.0 mg	Fatty acids, total polyunsaturated	0.048 g

Pre-cooling

They should be cooled to 4.4 °C as soon as possible after harvest (Ryall and Lipton 1979). Hydro-cooling, package-icing and forced-air cooling are acceptable for kohlrabi both with tops and with their tops removed (Toivonen and Forney 2002). Holmes and Kemble (2009) recommended room cooling for Kohlrabi grown in the southern United States.

Postharvest physiology

Respiration rate was given in mg CO₂ kg⁻¹ h⁻¹ as: 10 at 0 °C, 16 at 5 °C, 31 at 10 °C and 46 at 15 °C, and its ethylene production rate was less than 0.1 µl kg⁻¹ h⁻¹ at 20 °C (Toivonen and Forney 2002).

Storage

Coating with an 8% emulsion of carnauba wax reduced weight loss during storage at 18–21 °C (Weichmann 1987). He also stated that it was highly perishable because it develops fibres during storage making it unmarketable therefore it should not be kept longer than 2–4 days. In trials with the cultivar White Vienna moderate irrigation, low nitrogen rates (50 kg per hectare) and storage at 1.7 °C gave the best

keeping quality (Bhatnagar *et al.* 1986). Refrigerated storage recommendations include:

- 0–0.6 °C (Wardlaw 1937).
- 0 °C and 90–95% r.h. for 2–4 weeks (Phillips and Armstrong 1967, Lutz and Hardenburg 1968).
- 0 °C and 95% r.h. for 1 month (Ryall and Lipton 1979).
- 0 °C and 95% r.h. for up to 30 days (Tindall 1983).
- 0 °C and 95–100% r.h. for 25–30 days (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 2–4 weeks (Snowdon 1991).
- 0 °C and 98–100% r.h. for 2–3 months, but storage life is 2–4 weeks if tops are not removed (Cantwell 1997).
- Storage at about 3 °C for limited period only as discolouration takes place. In the United Kingdom, Kohlrabi is usually only sold fresh (Red Tractor 2008).
- 0 °C and 98–100% r.h. for 2–3 months Kohlrabi grown in the southern United States (Holmes and Kemble 2009).

Controlled atmosphere storage

Escalona *et al.* (2007) found that storage in air at 0 °C in high humidity resulted in yellowing of the stalks that later fell off. This affected their appearance and marketability. Whole or fresh-cut Kohlrabi could be stored for 28 days at 5 °C and 95% r.h. in 5% O₂ + 15% CO₂ followed by 3 days at 15 °C and 60–70% r.h. in air and still retain good commercial quality without detrimentally affecting the stalks. However, SeaLand (1991) had previously reported that controlled atmosphere storage had only a slight to no effect, and Cantwell (1997) reported that there is no benefit of controlled atmosphere storage.

Modified atmosphere packaging

Topped kohlrabi can be stored in perforated film to retard moisture loss (Ryall and Lipton 1979). Storage in 20 µm thick anti-mist OPP bags reduced weight loss and development of bacterial soft rot and black rots and extended the storage life to 60 days at 0 °C plus 3 days at 12 °C (Escalona *et al.* 2007). The equilibrium atmosphere inside the bags was 4.5–5.5% O₂ and 11–12% CO₂.

Hypobaric storage

Bangerth (1974) reported better leaf retention in storage at 2–4 °C in 75 mm Hg compared with those stored in atmospheric pressure.

Diseases

As with other Brassicas bacterial rots occur during storage especially bacterial soft rot (*Erwinia carotovora*) and black rot (*Xanthomonas campestris* pv. *campestris*) (Snowdon 1991).

Kudzu

Fabaceae, Leguminosae

Pueraria lobata (Willd.) Ohwi synonymous with *P. thunbergiana* (Siab. and Zuva) Bouth., *P. hirsuta* Schneid. non Kurz., *P. triloba* (Lour.) Makino. and *P. tuberosa* (Roxb.) DC. Other *Pueraria* species are morphologically similar, and sometimes they are referred to as kudzu including *P. edulis*, *P. montana*, *P. phaseoloides* and *P. thomsoni*, and they can also hybridize (Jewett *et al.* 2003). Other common names include arrowroot vine and Japanese arrowroot. *P. lobata* is believed to have originated in the China/Japan region of eastern Asia, where it is still cultivated for the edible roots, especially in China. It was at one time a staple food in Southeast Asia and Oceania. It was introduced into India in the 1920s, but was not as successful as *P. tuberosa* which has long been cultivated there. These two species, along with one or two other species of *Pueraria*, are now widely cultivated in the tropics and subtropics, mainly as a cover crop in regions liable to soil erosion (Kay 1987). It was introduced into the United States as a food plant, but became popular as a crop for erosion control. However, it quickly spread out of control and has assumed pest proportions in some areas. In some southern parts of the United States it has become an invasive species that climbs over shrubs and trees and can reduce yields or even kill them by heavy shading.

Pueraria is a small genus of perennial twining herbs or shrubs with tuberous roots. *P. lobata* is a vigorous vine, which climbs or trails over the ground with stolons rooting at the nodes. The flowers are borne in dense, pubescent racemes 20–50 cm long, are mauve to violet and fragrant. The pods are flat, oblong-linear, 5–10 cm long, hairy with 8–20 seeds. *P. tuberosa* is

generally similar but the racemes are slightly longer, and the flowers are blue to purplish-blue; the pods contain 3–5 seeds. In both species the roots are elongated and often tuberous and may reach to as much as 1 m in length and 40 cm in diameter and weigh up to 40 kg. They are starchy in both *P. lobata* and *P. tuberosa* and up to 60 cm long and 30 cm in diameter weighing up to 35 kg or even larger on older plants (Kay 1987).

A typical analysis of the edible portion of *P. lobata* tubers shown that they had moisture 68.6%, carbohydrate 27.1%, protein 2.1%, fat 0.1%, fibre 0.7%, ash 1.4%, calcium 15 mg 100 g⁻¹, iron 0.6 mg 100 g⁻¹ and phosphorus 18 mg 100 g⁻¹. A glycoside daidzin, an aglycone daidzein and an isoflavone puerarin were among compounds identified in the roots. An essential oil has been obtained from the leaves, which has been identified as 2-methoxy-4 vinylphenol, 2-methoxy-5-vinylphenol, damascenone, phytol, megastigmatrienones, 3-hydroxy-13-ionone and 3-hydroxy-13-damascone. No comparable analysis of *P. tuberosa* was available, but it has been reported to contain as much as 28% crude fibre on a dry weight basis and starch, sucrose, glucose, fructose and 13-sitosterol (Shibata *et al.* 1978, Kay 1987).

For harvesting the roots are dug by hand: the depth to which they penetrate and the irregular pattern in which they grow (from rooting stolons) do not lend itself to mechanization. A considerable amount of searching among the tangled vines may be necessary to locate suitable roots (Kay 1987).

Kywae

Dioscoreaceae

Dioscorea daemona Roxb. grows in the East Indies and produces very acrid roots that are eaten by the Karen or Tinguian people in times of scarcity (Cole 1922).

Leeks

Alliaceae, Liliaceae

Allium ampeloprasum var. *porrum* (L.) J. Gay synonymous with *Allium porrum* L. USDA (2013) also gave the following: *A. ampeloprasum* L. var. *ampeloprasum*, *A. ampeloprasum* L. called the broadleaf wild

Table 73 The composition of leeks for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	83.00 g	Thiamine	0.060 mg
Energy	61 kcal	Riboflavin	0.030 mg
Protein	1.50 g	Niacin	0.400 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.233 mg
Carbohydrate, by difference	14.15 g	Folate, DFE	64 µg_DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Sugars, total	3.90 g	Vitamin A, RAE	83 µg_RAE
Calcium	59 mg	Vitamin A, IU	1667 IU
Iron	2.10 mg	Vitamin E (α-tocopherol)	0.92 mg
Magnesium	28 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus, P	35 mg	Vitamin D	0 IU
Potassium, K	180 mg	Vitamin K (phylloquinone)	47.0 µg
Sodium, Na	20 mg	Fatty acids, total saturated	0.040 g
Zinc, Zn	0.12 mg	Fatty acids, total monounsaturated	0.004 g
Vitamin C, total ascorbic acid	12.0 mg	Fatty acids, total polyunsaturated	0.166 g

leek, *A. atroviolaceum* Boiss. also called the broadleaf wild leek, *A. porrum* L. called the garden leek, *A. burdickii* (Hanes) A.G. Jones called the narrow leaf wild leek, *A. scorodoprasum* L. called the Sand Leek, *A. scorodoprasum* L. ssp. *rotundum* (L.) Stearn also called the sand leek and *A. triquetrum* L. called the three-cornered leek. It is a cultigen of the wild *A. ampeloprasum*, which is native to the Levant and was grown in Europe in the Middle Ages (Purse-glove 1972). Total world production of leeks, other alliaceous vegetables, in 2010 was estimated by FAO (2012) as 2,046,566 tonnes.

It is a robust perennial plant with little or no bulb formation and normally grows up to about 1 m high. The edible portion is the leaves and the immature bulbs. They will freeze at about -1.9 to -1.2 °C (Wright 1942). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 73.

Harvesting

They are harvested by pulling the tops when they are judged to be thick enough for the market. On dry heavy soils it may be necessary to prise the roots with a spade or fork. The roots are trimmed close

to the base taking care not to damage the base plate otherwise they can discolour and the outer leaves become detached. They should be free from seed stalks and the bottom 2 or 3 cm should be white with the rest dark green.

Pre-cooling

Forced air cooling with high humidity air and hydro-cooling were the most suitable method, air cooling in a conventional cold store was also suitable and vacuum cooling was less suitable (MAFF n.d.) (Figure 37).

Respiration

Leeks produce levels of ethylene of less than 0.1 µl kg⁻¹ h⁻¹ but are moderately sensitive to ethylene since exposure can result in softening and increased decay (DeEll 2002). Respiration rates were given by Hruschka (1978) as 10–20 at 0 °C, 20–29 at 4.4 °C, 50–70 at 10 °C, 75–117 at 15.6 °C, 110 at 21 °C and 107–119 mg CO₂ kg⁻¹ h⁻¹ at 26.7 °C. Low O₂ levels were shown to reduce respiration rate at a variety of temperatures (Table 74). Respiration rate was given as 10–20 ml CO₂ kg⁻¹ h⁻¹ at 5 °C (Weichmann 1987).

Storage

At room temperature of 20 °C and 60% r.h. the fruit could be kept for 1–2 days (Mercantilia 1989). Humidity has a substantial effect on weight loss and therefore quality since where leeks lose a lot of weight



Figure 37 Leeks being washed after preparation for the market.

Table 74 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Musselburgh leeks (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	20	28	50	75	110
In 3% O ₂	10	–	30	–	57

they become flaccid and unmarketable. Storage losses due to decay and trimming at 0–1 °C over a 14-week period were 45–75% in 90–95% r.h. and 25–55% in 98–100% r.h., while weight loss was 2.4–2.6% at 90–95% r.h. and 0.5–0.9% for 98–100% r.h. (Weichmann 1987). Refrigerated storage recommendations were:

- 0 °C and 85–90% r.h. for 1–3 months (Wardlaw 1937, Hardenburg *et al.* 1990).
- 0–1 °C and 90–95% r.h. for 1–3 months (Anonymous 1967).
- 0 °C and 90–95% r.h. for 1–3 months (Phillips and Armstrong 1967, Pantastico 1975).
- 0 °C and 90–95% r.h. for 28–80 days (Tindall 1983).
- –1 °C and 90–95% r.h. for 42 days (Mercantilia 1989).
- 1 °C and 90–95% r.h. for 25 days (Mercantilia 1989).
- 4 °C and 90–95% r.h. for 15 days (Mercantilia 1989).
- 8 °C and 90–95% r.h. for 8 days (Mercantilia 1989).
- 0 °C and 90–95% r.h. for 3–4 weeks, at –1 °C the maximum storage period can be extended by a few days (Goffings and Herregods 1989).
- 0 °C and 90–95% r.h. for 1 week (Hardenburg *et al.* 1990).
- 0 °C and 95–100% r.h. (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 1–3 months (Snowdon 1991).
- 0 °C and 95–100% r.h. for 2–3 months (DeEll 2002).

Controlled atmosphere storage

Goffings and Herregods (1989) showed that storage at 0 °C and 94–96% r.h. in 2% CO₂ + 2% O₂ + 5% carbon monoxide leeks could be stored for up to 8 weeks compared to 4 weeks at the same temperature in air. Under those conditions the total losses were

19%, while those stored in the same conditions but without carbon monoxide had 28% losses and those in air had 37% losses. Lutz and Hardenburg (1968) reported that CO₂ levels of 15–20% caused injury. CO₂ levels of 15–20% can cause injury (Lutz and Hardenburg 1968), but controlled atmosphere storage had variable effects as the following recommendations:

- 0 °C in 15–25% CO₂ for 4 1/2 months (Monzini and Gorini 1974)
- 1–3% O₂ with 5–10% CO₂ at 0 °C for up to 4–5 months (Kurki 1979).
- 0–5 °C with 3–5% CO₂ and 1–2% O₂, which had a good effect but was of no commercial use (Kader 1985, 1992).
- 0–5 °C with 5–10% CO₂ and 1–6% O₂, which had only a slight effect (Saltveit 1989).
- 0 °C with 3–5% CO₂ and 1–2% O₂ (SeaLand 1991).

Hypobaric storage

Ward (1975) reported no advantages in storage at 75 mm Hg compared to atmospheric pressure.

Modified atmosphere packaging

Leeks held in polyethylene-lined crates remain saleable for 5–6 weeks at 0 °C under crushed ice, 4 weeks at 0 °C without ice, less than 2 weeks at 4.4 °C and 13 days at 10 °C. Leeks stored in non-lined crates kept for 3 weeks at 0 °C, 8 days at 4.4 °C and 7 days at 10 °C, with or without crushed ice (Hruschka 1978, DeEll 2002).

Lesser yam

Dioscoreaceae

Dioscorea esculenta (Lour.) Burk. *D. esculenta* var. *spinosa* and *D. esculenta* var. *fasciculata* were a former classification based on the presence or absence of prickles on the tubers but is no longer recognized (Kay 1987). It is also synonymous with *D. fasciculata* Roxb. (Coursey 1968). Other common names include lesser Asiatic yam, sweet yam, Chinese yam, ñame azucar, couche-couche douce, igname des blancs, kangar, Karen potato, kizahangu and kodi. Its origin was within the area of India, Vietnam, Papua New

Guinea or the Philippines and is now grown widely throughout the tropics (Kay 1987). It was referred to as a *staple food* in southern China from the 2nd and 3rd centuries CE. Sturtevant (1892) stated for *D. fasciculata* 'Tropical eastern Asia. This species is cultivated largely about Calcutta, and a starch is made from its tubers. Firminger (1874) says that this is a very distinct kind of yam, the tubers about the size, form and colour of large kidney potatoes; when it is well cooked, it has a greater resemblance in mealiness and flavour to the potato than any other yam he knows of. It is much cultivated in the Philippines by the natives and is much esteemed.'

It is a vine usually up to 3 m long with thin stems up to 3 mm in diameter that may be smooth or prickly. The leaves are alternate, almost round, but pointed at the tips and deeply lobed at the base, finely hairy and about 10 cm in diameter. The petioles are thickened at the base with four sharp prickles. Flowers are rare but when they occur, they are larger than those of most other *Dioscorea* spp. The roots are fibrous, often more or less prickly. Tubers are formed as swellings at the end of stolons that are borne in clusters, as in potatoes (*Solanum tuberosum*), with up to 20 tubers per plant. They resemble long, narrow sweetpotatoes but can also be spindle shaped or branched. In the West Indies the tubers usually weigh up to 200 g and are up to 10 cm long and 5 cm in diameter, but in Papua New Guinea some varieties produce tubers weighing up to 3 kg (Kay 1987).

Opara (1999) gave the following analysis per 100 g of the tuber as water 70–74 g, carbohydrate 24–25 g, protein 1.5–3.5 g and fibre 0.8 g. Kay (1987) reported the composition of the edible part as water 67–81%, protein 1.29–1.87%, fat 0.04–0.29%, carbohydrate 17–25%, fibre 0.18–1.51% and ash 0.5–1.24%. The carbohydrate was mainly starch but with 7–11% of sugars. Shajeela *et al.* (2011) reported the following per 100 g fresh weight: starch 62.40 ± 0.44 g, niacin 41.36 ± 0.35 g and ascorbic acid 84.06 ± 0.24 g. Knoth (1993) gave the following analysis on a fresh weight basis: 67–81% moisture, 17–25% carbohydrates, 0.1–0.3% fats and 1.3–1.9% crude protein. Shajeela *et al.* (2011) gave the following analysis for anti-nutritional factors per 100 g⁻¹ fresh weight: total free phenolics 0.79 ± 0.07 g, tannins 0.20 ± 0.01 g, hydrogen cyanide 0.21 ± 0.03 mg, total oxalate 0.33 ± 0.02 g, amylase inhibitor 7.80 AIU

mg⁻¹ soluble starch trypsin inhibitor and 1.92 ± 0.07 TIU mg⁻¹ protein.

Curing

Ravindran and Wanasundera (1993) successfully cured tubers by exposing them for 3 days after harvest to mean ambient conditions of 29 °C and 84% r.h. Martin *et al.* (1974) recommended 26–28 °C and high humidity for 5–7 days. Wilson (1980) described a simple method of curing *D. esculenta*. The tubers were first stacked on the ground in a lightly shaded area and covered with grass or mats. Then a canvas tarpaulin was placed over the whole stack to cover the grass or mats ensuring that the tarpaulin does not touch the yams. As an alternative, a simple wooden frame could be built and the canvas draped like a tent over the piled yams. She indicated that plastic sheets should not be used for curing since it can make the yams too hot. If there is no canvas tarpaulin, then several layers of sacks or mats could be used.

Harvesting

This is usually 6–10 months after planting when the vines begin to turn yellow. The dormancy period is very short so harvesting should not be delayed. Commercial potato harvesting machines can be used for the lesser yam when they are planted on ridges (Kay 1987).

Sprouting

The dormancy period of *D. esculenta* was 4–8 weeks from the Caribbean and 12–18 weeks from Nigeria/West Africa (Opara 1999, Passam 1982). Tubers were stored in thin layers on the floor of a well-ventilated room in ambient conditions of 24–28 °C and 70–90% r.h. for 150 days. They started to sprout after 120 days. Crude protein, starch and ascorbic acid content decreased significantly during the first 60 days of storage, but the decrease was gradual thereafter. Losses of some minerals and a significant reduction in levels of oxalates were also noted during storage (Ravindran and Wanasundera 1993). Tubers of the cultivars Sree Priya and Sree Subra stored at room temperature of 30–32 °C and 80–85% r.h. in the dark sprouted 70–80 days after harvest. In the apical and basal regions, the starch

content decreased while the sugars and α -amylase activity increased (Muthukumarasamy and Panneerselvam 2000). Passam (1982) showed that postharvest treatment with gibberellins could delay sprouting, but no records were found of its commercial use and postharvest uses of gibberellins are not permitted in all countries. The effect of maleic hydrazide in controlling sprouting in yam showed that soaking the tubers in 1000 μL^{-1} solutions for 10 h before storage reduced the rate of sprouting by 16% (Ramanujam and Nair 1982).

Storage

Ventilated storage at about 25 °C for up to 60 days has been recommended (Tindall 1983, Opara 1999). Uninjured tubers can be stored for 4 months or more in ambient tropical temperatures in well-ventilated stores (Kay 1987).

Diseases

Tubers may be infected with *Botryodiplodia theobromae*, *Lasiodiplodia* sp. and *Fusarium* spp. causing postharvest diseases (Kay 1987).

Lettuce

Compositae

Lactuca sativa L. Saltveit (2002) divided into four distinct types as:

- Crisphead or Iceberg (*L. sativa* var. *capitata*) that produces large, heavy, compact folded heads with crisp, brittle, prominently veined leaves.
- Butterhead, Bib or Boston (*L. sativa* var. *capitata*) forms open heads with softer leaves having a smooth texture.
- Cos or Romaine (*L. sativa* var. *longifolia*) does not form a true head, but is composed of upright, large, elongated and often coarser leaves.
- Leaf (*L. sativa* var. *crispa*) also does not produce a head, and the leaves are more spreading, delicate, smaller and less elongate than cos.

Purseglove (1972) stated that its centre of origin was the Middle East with its depiction on Egyptian tombs dating to 4500 BCE. It was grown by the ancient Greeks and Romans and the Moors developed many

types. It reached China in the 7th century CE. Most authorities consider it a cultigen of *L. serriola* L., a prickly biennial from Europe, western Asia and northern Africa. Others report that its origin was from hybridization; perhaps between *L. saligna* L. and *L. serriola* since these two species are interfertile and natural hybrids do occur. It is an annual herb forming a dense basal rosette of leaves and subsequently tall branched flowering stems. The edible portion is the leaves. Some cultivars produce hearts where the leaves in the centre are closely compact, pale green or yellow and crisp and tender while other types have loosely arranged leaves. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 75. Total world production of lettuce and chicory in 2010 was estimated by FAO (2012) as 24,239,977 tonnes.

Preharvest factors

Luna *et al.* (2012) studied the effects of five drip irrigation systems on the postharvest quality fresh-cut iceberg lettuce. The irrigation regimes they used were the recommended rate, an excess of 50%, an excess of 25%, a deficit of 25% and a deficit 50%. They found that visual quality was lower on those from the highest irrigation regime and the leaves had increased off-odours. Also the midrib tissue had a more than 17-fold increase in PAL activity from the highly irrigated lettuce. They concluded that the quality and shelf life of the fresh-cut lettuce was better preserved by reduced irrigation.

Harvesting

For 'hearting' cultivars harvesting should be just when the heart is firm, but before it begins to bolt, that is the flower stalk begins to grow. When they bolt they lose their crisp texture, become tough and may have a bitter taste. Firmness, or what is usually called solidity, can be used for assessing harvest maturity. Saltveit (2002) reported that firm heads store best, while hard and extra-hard heads are more prone to develop russet spotting, pink rib and other physiological disorders. The harvester slightly presses the lettuce with their thumb and fingers on the basis of how much it yields to this pressure. Normally the back of the hand is used for testing the firmness of lettuce in order to avoid damage. Some growers leave

Table 75 The composition of lettuce for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Butterhead including Boston and Bibb types	Cos or Romaine	Iceberg including Crisphead types	Green leaf
Water (g)	95.63	94.61	95.64	94.98
Energy (kcal)	13	17	14	15
Protein (g)	1.35	1.23	0.90	1.36
Total lipid (fat) (g)	0.22	0.30	0.14	0.15
Carbohydrate, by difference (g)	2.23	3.29	2.97	2.87
Total dietary fibre (g)	1.1	2.1	1.2	1.3
Sugars, total (g)	0.94	1.19	1.97	0.78
Calcium (mg)	35	33	18	36
Iron (mg)	1.24	0.97	0.41	0.86
Magnesium (mg)	13	14	7	13
Phosphorus (mg)	33	30	20	29
Potassium (mg)	238	247	141	194
Sodium (mg)	5	8	10	28
Zinc (mg)	0.20	0.23	0.15	0.18
Total ascorbic acid (mg)	3.7	4.0	2.8	9.2
Thiamine (mg)	0.057	0.072	0.041	0.070
Riboflavin (mg)	0.062	0.067	0.025	0.080
Niacin (mg)	0.357	0.313	0.123	0.375
Vitamin B-6 (mg)	0.082	0.074	0.042	0.090
Folate (µg_DFE)	73	136	29	38
Vitamin B-12 (µg)	0	0	0	0
Vitamin A (µg_RAE)	166	436	25	370
Vitamin A (IU)	3312	8710	502	7405
Vitamin E (α-tocopherol) (mg)	0.18	0.13	0.18	0.22
Vitamin D (D2 + D3) (µg)	0	0	0	0
Vitamin D (IU)	0	0	0	0
Vitamin K (phyloquinone) (µg)	102.3	102.5	24.1	126.3
Fatty acids, total saturated (g)	0.029	0.039	0.018	0.020
Fatty acids, total monounsaturated (g)	0.008	0.012	0.006	0.006
Fatty acids, total polyunsaturated (g)	0.117	0.160	0.074	0.082

harvesting to late morning or early afternoon because where they are too turgid the leaves are soft and more susceptible to bruising (John Love, quoted by Thompson 1996).

Diffuse reflectance measures the reflected light just below the surface of the crop and can be used for maturity measurement. In lettuce there was a shift in diffuse reflectance from 640–660 nm to 700–750 nm during maturation, which could be used to determine harvest maturity (Brach *et al.* 1982). A lettuce harvester was developed by Lenker and Adrian (1971) which used X-rays to determine which heads were sufficiently mature for harvesting. Garrett and Talley (1970) used γ rays for the same purpose. The basis of these tests depends on the rate of transmission of the rays through the lettuce, since this depends on the density of the head, which increases as it matures.

Harvesting is by cutting them just below the soil surface or pulling them from the ground and trimming off the roots, outer leaves and any necrotic, diseased or damaged leaves. Harvesting should not be carried out when there is rain or dew as they are more easily damaged (Pantastico 1975). Mechanical aids to harvesting involve cutting by hand and placing it on a conveyer on a mobile packing station, which is slowly conveyed across the field.

Pre-cooling

Vacuum cooling was the most suitable, forced air cooling with high humidity was also suitable and air cooling in a conventional cold store was less suitable and hydrocooling was generally unsuitable (MAFF n.d.). Vacuum cooling is used for most lettuce marketed in Europe and the United States, in spite of

the high cost mainly because the method is so quick. After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of -1.7 to 0°C , the lettuce temperature fell from 20 – 22°C to 1°C (Barger 1963). Top icing as soon as they are harvested is used when the lettuces are packed into crates or waxed cartons (Lutz and Hardenburg 1968). This may be done directly in the field or at the packhouse. Perforated polyethylene film is used as head wraps or plastic film box liners to reduce weight loss. If the crop is to be vacuum cooled the film must be perforated.

Prestorage treatments

Butterhead lettuce treated with 1-MCP had a reduced respiration rate and ethylene production and russet spotting was retarded and the ascorbic acid level was retained compared with those that were not treated during 12 days of storage at either 2 or 6°C (Tay and Perera 2004). Lettuce that had been soaked in 1% ascorbic acid solution before being vacuum packed retained their green colour better than those not treated with ascorbic acid (Pospilšil *et al.* 2003). Xue-tong *et al.* (2003) suggested irradiation of modified atmosphere packs of fresh-cut iceberg lettuce with γ irradiation at 0.5 – 1 kGy to slow oxidation processes and to improve sensory properties. Treatment with warm water was shown to reduce the undesirable effects of the treatment. There is evidence that ozone is phytotoxic to lettuce, which is damaged by exposure to as little as $0.5 \mu\text{L L}^{-1} \text{O}_3$.

Carbon monoxide

With levels of O_2 between 2 and 5%, carbon monoxide can inhibit discolouration of lettuce on the cut butts or from mechanical damage on the leaves. Concentrations of carbon monoxide in the range of 1–5% were effective, but the effect was lost when the lettuce was removed to normal air at 10°C . The respiration rate of lettuce was reduced during a 10-day storage period at 2.5°C when carbon monoxide was added to the store. However, low concentrations of carbon monoxide in the store atmosphere can increase the levels and intensity of the physiological disorder called russet spotting (Table 76).

Table 76 The effect of carbon monoxide on the development of russet spotting on harvested lettuce (source: adapted from Kader 1987)

Carbon monoxide concentration ($\mu\text{L L}^{-1}$)	Russet spotting score
0	0a
80	16c
400	22d
2,000	24d
10,000	20d
50,000	6b

Figures followed by the same letter were not significantly different ($p = 0.05$) by the Duncan's Multiple Range Test.

Table 77 The effect of ethylene on the development of russet spotting on harvested lettuce (source: adapted from Kader 1987)

Ethylene concentration ($\mu\text{L L}^{-1}$)	Russet spotting score
0	0
0.01	4
0.1	20
1	36
10	32

Table 78 Effects of temperature and reduced O_2 level on the respiration rate (CO_2 production in $\text{mg kg}^{-1} \text{h}^{-1}$) of three cultivars of lettuce (source: adapted from Robinson *et al.* 1975)

Temperature ($^{\circ}\text{C}$)	In air					In 3% O_2		
	0	5	10	15	20	0	10	20
Unrivalled	18	22	26	50	85	15	20	55
Korlaat	9	11	17	26	37	7	12	25
Kloek	16	24	31	50	80	15	25	45

Postharvest physiology

Discolouration of lettuce is associated with ethylene. This can take the form of russet spotting or a rusty brown discolouration on the leaves (Kader 1985). It is usually eliminated by storage at 0°C , but is increased by ethylene in the storage atmosphere (Table 77) (Anonymous 1968). Inaba *et al.* (1989) found that there was no response in respiration rate to ethylene at $100 \mu\text{L L}^{-1}$ for 24 h at any temperature between 5 and 35°C . Robinson *et al.* (1975) showed that there were large differences in respiration rate for different cultivars (Table 78). Saltveit (2002) gave their respiration rate in Table 79

Table 79 Respiration rate in milligrams carbon dioxide per kilogram per hour for two types of lettuce at different temperatures (source: adapted from Saltveit 2002)

Temperature (°C)	Head lettuce	Leaf lettuce
0	6–17	19–27
5	13–20	24–35
10	21–40	32–46
15	32–45	51–74
20	51–60	82–120
25	73–91	120–173

Storage

At room temperature of 20 °C and 60% r.h. they could be kept for about 2 days (Mercantilia 1989). Rubinskiene *et al.* (2008) stored fresh-cut iceberg lettuce of the cultivar Elena at either 1 ± 1 °C or 6 ± 1 °C either vacuum packed or package without vacuum. Lettuce stored at 1 °C had better ascorbic acid retention with no effect of vacuum packaging, but at 6 °C those in vacuum packs had better ascorbic acid retention. Generally the retention of quality was optimum at 1 °C in vacuum packs. They will freeze at about -0.6 to -0.3 °C (Wright 1942) or -0.39 to -0.17 °C (Weichmann 1987). Refrigerated storage recommendations are as follows:

- 0 °C for 30 days with 2.5% weight loss (Platenius *et al.* 1934).
- 4.4 °C for 20 days (Platenius *et al.* 1934).
- 10 °C for 6 days (Platenius *et al.* 1934).
- 0 °C and 95% r.h. for 2–3 weeks (Wardlaw 1937, Hardenburg *et al.* 1990, Phillips and Armstrong 1967, Anonymous 1968).
- 0–1 °C and 90–95% r.h. for 1–3 weeks or 4–6 weeks (Iceberg type) (Anonymous 1967).
- 0–1 °C and 95% r.h. for 7 days (Shipway 1968).
- 0 °C and 90–95% r.h. for 1 week (leaf) (Pantastico 1975).
- 0–3 °C and 90–95% r.h. for up to 14 days with up to 15% weight loss (Tindall 1983).
- 0 °C and 90–95% r.h. for 12 days for Butterhead (Mercantilia 1989).
- 0 °C and 90–95% r.h. for 8–12 days for Butterhead (SeaLand 1991).
- 2 °C for 8 days for Butterhead (Mercantilia 1989).
- 4 °C for 6 days for Butterhead (Mercantilia 1989).

- 8 °C for 4 days for Butterhead (Mercantilia 1989).
- 12 °C for 2 days for Butterhead (Mercantilia 1989).
- 0 °C and 90–95% r.h. for 14 days for Crisphead (Mercantilia 1989).
- 4 °C for 9 days for Crisphead (Mercantilia 1989).
- 8 °C for 6 days for Crisphead (Mercantilia 1989).
- 20 °C for 2 days for Crisphead (Mercantilia 1989).
- 0 °C and 90–95% r.h. for 9–14 days for Iceberg (SeaLand 1991).
- 0 °C and 95–100% r.h. for 14–21 days for head lettuce (SeaLand 1991).
- 0–1 °C and 95–100% r.h. for 1–4 weeks (Snowdon 1991).
- 0 °C and 98–100% r.h. for a maximum of 4 weeks, depending on variety, and about half that time at 5 °C (Saltveit 2002).

Controlled atmosphere storage

Low O₂ levels in storage reduced the respiration rate of all three cultivars studied, but low O₂ was more effective at the higher temperatures (Table 78).

CO₂ above 2.5% or O₂ levels below 1% can injure lettuce (Hardenburg *et al.* 1990). 1.5% CO₂ with 3% O₂ inhibited butt discolouration and pink rib at 0 °C, but the effect did not persist during 5 days subsequent storage at 10 °C (Hardenburg *et al.* 1990). Physiological disorders associated with high CO₂ include brown stain on the midribs of leaves (Stewart and Uota 1971), which can be caused by storage in levels of CO₂ of 2% or higher especially if combined with low O₂ (Haard and Salunkhe 1975). Ke and Saltveit (1989) also found that storage in elevated levels of CO₂ can result in brown stain that develops when they are transferred from greater than 2% CO₂ to air at 10 °C. Storage for 42 h in 30% CO₂ resulted in the lettuce producing the high levels of ethanol at 28 °C but very little was produced by those stored at 8 °C in the same CO₂ level (Yanez Lopez *et al.* 1998). Other storage recommendations are:

- 0 °C with 0% CO₂ and 1–8% O₂ (Haard and Salunkhe 1975).
- 3–5% CO₂ + 15% O₂ for 3 weeks (Tataru and Dobreanu 1978).
- 0–5 °C with 0% CO₂ and 2–5% O₂ or 0–5 °C with 0% CO₂ (Kader 1985).

- 0 °C with 98% r.h. in a maximum of 1% CO₂ and a minimum of 2% O₂ (Fellows 1988).
- 0–5 °C with 0% CO₂ and 1–3% O₂ for leaf, head and cut and shredded lettuce, the effect on the former was moderate and on the latter it had a high level of effect (Saltveit 1989).
- 1 °C with 3% CO₂ and 1% O₂ for 21 days with less loss in ascorbic acid than those stored in air (Adamicki 1989).
- 0 °C with 2% CO₂ and 3% O₂ for a month (Hardenburg *et al.* 1990).
- 0 °C with 0% CO₂ and 2–5% O₂ (SeaLand 1991).
- 1–3% O₂ which had a good effect and was of some commercial use when carbon monoxide was added at the 2–3% level (Kader 1992).
- 1.5% CO₂ + 3% O₂ (Lawton 1996).
- 0–5 °C in 0% CO₂ + 1–3% O₂ (Bishop 1996).
- 0–5 °C in 1–3% O₂ to reduce russet spotting in susceptible lots (Saltveit 2002).

Hypobaric storage

It was claimed that hypobaric storage increased their storage life from 14 days in conventional cold stores up to 40–50 days (Haard and Salunkhe 1975). However, Ward (1975) and Bangerth (1973) found no improvement in storage at 70 mm Hg and 75 mm Hg, respectively, and Burg (2004) reported an increase in the physiological disorder, pink rib, when they were exposed to 30 or 80 mm Hg at 0–1 °C for 4 weeks. Conversely Burg (2004) also quoted Jamison (1980) that storage at 0.5 °C and 90–95% r.h. in 10, 20, 40 or 80 mm Hg resulted in the lettuce remaining in excellent condition after 63 days of storage. The lettuce that had been stored in the same conditions at atmospheric pressure had significant incidence of pink rib, black heart and decay after only 37 days of storage. Burg (2004) also reported that by the manufacturer of hypobaric storage containers, Grumman Allied Industries, investigated marginal and pink discolouration and found that during storage at 5 mm Hg over 35 days the disorder was 'eliminated'. However, it was 'progressively accentuated' at 10–40 mm Hg and 'then decreased in frequency as the pressure was increased from 80 to 160 mm Hg'. It was concluded that the best storage conditions was 2 °C and 5 mm Hg for 21 days but when the lettuce was stored for 36 days there was a high incidence of russet spotting. Duck Soon An *et al.* (2009) studied

packaging of curled lettuce in small rigid containers at different hypobaric conditions. In both 190 and 380 mm Hg the lettuce had high moisture loss without any observable benefit in keeping quality compared with atmospheric pressure storage.

Modified atmosphere packaging

Cameron (2003) found that at 5 °C browning was retarded when O₂ was below 1%, while fermentation occurred below 0.3–0.5% O₂ therefore modified atmosphere packaging that gave an atmosphere between 0.5 and 1% O₂ was recommended. Escalona *et al.* (2006) concluded that 80% O₂ should be used in MA packaging of fresh-cut Butter lettuce in combination with 10–20% CO₂ to reduce their respiration rate and avoid fermentation.

Diseases

Postharvest diseases that have been reported on lettuce include:

- Bacterial leaf spot and head rot *Xanthomonas campestris* pv. *vitians* (Brown) Dye.
- Bacterial soft rot *Erwinia carotovora* (Jones) Bergey *et al.* and *Pseudomonas marginalis* (Brown) Stevens.
- Grey mould *Botrytis cinerea* Pers.:Fr., teleomorph: *Botryotinia fuckeliana* (de Bary) Whetzel.
- Sclerotinia rot or Watery soft rot *Sclerotinia sclerotiorum* (Lib.) de Bary and *S. minor* Jagger.
- Southern blight or Sclerotium rot *Sclerotium rolfsii* Sacc. teleomorph: *Athelia rolfsii* (Curzi) Tu & Kimbrough.
- Bottom rot *Rhizoctonia solani* Kühn teleomorph: *Thanatephorus cucumeris* (A.B. Frank) Donk.
- Cercospora leaf spot *Cercospora longissima* Sacc.
- Downy mildew *Bremia lactucae* Regel and *Plasmopara lactucae-radicis* Stanghellini & Gilbertson
- Powdery mildew *Erysiphe cichoracearum* DC.
- Anthracnose *Microdochium panattonianum* (Berl.) = *Marssonina panattoniana* (Berl.) Magnus
- Septoria leaf spot *Septoria lactucae* Pass.
- Stemphylium leaf spot *Stemphylium botryosum* Wallr. teleomorph: *Pleospora tarda* E. Simmons.

Slimy breakdown of the tissue by bacteria often follows fungal infection by *Sclerotinia* and *Botrytis cinerea* and occurs postharvest. Trimming outer

infected leaves and storage at 0 °C reduced the severity of rotting. *Pseudomonas* spp. especially the fluorescent pseudomonads have been implicated in postharvest browning of lettuce owing to the presence of high populations on the leaf surface. This group comprise both saprophytic and pathogenic bacteria on the leaf surface and damage during handling or harvesting can be a major entry point for the bacteria (Pascoc *et al.* 2002). López-Gálvez *et al.* (2010) tested the suitability of 3 mg L⁻¹ aqueous chlorine dioxide as an effective sanitizer of fresh-cut iceberg lettuce stored under active modified atmosphere packaging in cold storage and compared it with 100 mg L⁻¹ sodium hypochlorite. They concluded that aqueous chlorine dioxide was as suitable as sodium hypochlorite with the advantage of preventing the formation of trihalomethanes.

Lima beans

Fabaceae, Leguminosae

Phaseolus lunatus L. synonymous with *P. inamoensis* L., *P. limensis* Macfad., *P. lunatus* L. var. *lunonanus* L.H. Baile and *P. tunkinensis* Lour. Other common names include butter beans and Burma beans. They originated in the American tropics and are now grown in tropical and subtropical areas around the world. The edible portion is the seed, which is produced in a pod or legume. The pods are up to 12 cm long and 2.5 cm wide and contain up to six seeds. The seeds are variable in size and can be divided into the large size ones called macrospermus that are about 2.5 cm long, which are thought to have originated in Mexico, and the small seeded type called microspermus or baby lima bean, which are about 1 cm long and probably originated in Peru. The seeds are usually white in colour, but can be red, purple, brown, black or even mottled. They will freeze at about -1.2 to -0.9 °C (Wright 1942) or -0.89 to -0.56 °C (Weichmann 1987). The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 80.

Harvesting and handling

The small types usually mature between 90 and 130 days after sowing, but the large seeded types take from 200 to 270 days depending on cultivar or variety.

Table 80 The composition of lima beans for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	70.24 g	Thiamine	0.217 mg
Energy	113 kcal	Riboflavin	0.103 mg
Protein	6.84 g	Niacin	1.474 mg
Total lipid (fat)	0.86 g	Vitamin B-6	0.204 mg
Carbohydrate, by difference	20.17 g	Folate	34 µg_DFE
Total dietary fibre	4.9 g	Vitamin B-12	0.00 µg
Sugars, total	1.48 g	Vitamin A	10 µg_RAE
Calcium	34 mg	Vitamin A	209 IU
Iron	3.14 mg	Vitamin E (α-tocopherol)	0.32 mg
Magnesium	58 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	136 mg	Vitamin D	0 IU
Potassium	467 mg	Vitamin K (phyloquinone)	5.6 µg
Sodium	8 mg	Fatty acids, total saturated	0.198 g
Zinc	0.78 mg	Fatty acids, total monounsaturated	0.050 g
Total ascorbic acid	23.4 mg	Fatty acids, total polyunsaturated	0.419 g

Green lima beans are harvested by hand when the seeds have become fully developed, but are still green so that they are still soft and tender. Several pickings are made at 4–5-day intervals. Mature lima beans are usually harvested when about three-quarters of the pods are yellow and dry and the rest have begun to turn from green to yellow. In the United States lima beans are harvested by machine, and there are several types of harvester on the market. Hydrocooling was recommended for the shelled beans (Lutz and Hardenburg 1968).

Storage

Storage information in this section refers to green lima beans, which may be marketed in their pods or as shelled beans. In the latter case they become sticky and their colour fades if they are stored for too long (Phillips and Armstrong 1967). After 3 or 4 weeks at 0 °C shelled beans became discoloured, which was attributed to desiccation and chilling injury by Wardlaw (1937). Refrigerated storage recommendations were:

- 0 °C for 15 days (Wardlaw 1937).
- 0–1 °C and 85–90% r.h. for 2–3 weeks (Anonymous 1967).

- 0 °C and 85–90% r.h. for 2 weeks or 4.4 °C and 85–90% r.h. for 4 days (Phillips and Armstrong 1967).
- 0–4.4 °C and 90% r.h. for beans in pods for 1 week (Lutz and Hardenburg 1968).
- 0 °C for 10–14 days, 21.2 °C for 8 days, 4.4 °C for 4–7 days for shelled beans (Lutz and Hardenburg 1968).
- 4.4–7.2 °C and 90–95% r.h. for 10–14 days with 12% loss for beans in pods (Pantastico 1975).
- 0–4.4 °C and 90% r.h. for 2 weeks for shelled beans (Pantastico 1975)
- –2.2 to 0 °C for 11 days (Purseglove 1968).
- 4–6 °C with high humidity for 5–6 days (Tindall 1983).
- 10 °C and high humidity for about 3 days (Tindall 1983).
- 0 °C and 90–95% r.h. for 7–10 days (SeaLand 1991).

Storage of fresh beans in 25–35% CO₂ inhibited fungal and bacterial growths without adversely affecting their quality (Pantastico 1975). Storage in perforated polyethylene bags was recommended by Lutz and Hardenburg (1968) or in sealed polyethylene bags by Pantastico (1975).

Liquorice

Fabaceae, Leguminosae

Glycyrrhiza glabra L. synonymous with *G. glandulifera* Waldst. & Kit. and *Liquiritiae officinalis* Moench. It was known to the ancient Greeks and has been grown in Britain from at least the 16th century. The West Yorkshire town of Pontefract became famous for producing liquorice sweets called Pontefract cakes. Russia and the Mediterranean region are major producers and exporters of the extract (Harrison *et al.* 1985). Related species of wild licorice include *G. asperrima* L. from Russia and Central Asia where the leaves are used by the Kalmucks as a substitute for tea, *G. echinata* L. from Southern Europe and the Orient and *G. lepidota* Pursh from North America where the root is eaten by the Indians of Alaska and the Northwestern States (Sturtevant 1892).

G. glabra is a perennial herb growing up to 1 m tall. Flowers are long, purple to pale whitish blue up to about 1.2 cm long produced in a loose inflorescence.

The fruit is a pod of 2–3 cm long. It has stoloniferous roots and harvesting is usually after 3–5 years by which time it will have formed an extensive root system (Harrison *et al.* 1985).

Fenwick *et al.* (1990) reported that ‘many of the early claims for the effectiveness of liquorice extracts, decoctions and potions have been shown by modern science to be credible, a root component (glycyrrhizin) being generally regarded as the major biologically active principle’. The flavour of liquorice comes mainly from a compound called anethole (trans-1-methoxy-4-[prop-1-enyl] benzene), an aromatic, unsaturated ether compound also found in anise, fennel, and several other herbs. The root also contains glycyrrhizin that is reported to be a sweeter than sugar. There are health benefits of liquorice. Chin *et al.* (2007) reported results of their search for new cancer chemopreventive agents. They isolated several compounds from *G. glabra* roots. Of these compounds, hispaglabridin B, isoliquiritigenin and paratocarpin B were found to be the most potent antioxidant agents. They also demonstrated that isoliquiritigenin could prevent the incidence of 1,2-dimethylhydrazine-induced colon and lung tumours in mice. Glycyrrhizin and its aglycone, glycyrrhetic acid, have been reported to induce interferon activity and augment natural killer cell activity and chalcones in liquorice possess antiviral activity against HIV. Glycyrrhizin also has anti-inflammatory and anti-allergic properties (Craig 1997). He also commented that some herbs are safe in modest amounts but they may become toxic at higher doses. For example, while liquorice root can be used safely for treating duodenal and gastric ulcers, deaths from its excessive use have been reported.

Lotus root

Nymphaeaceae, Nelumbonaceae

Nymphaeas lotus L., *Nelumbo nucifera* Gaertn. synonymous with *Nelumbium speciosum* Willd. and *N. nelumbo* Druce. Other common names include Indian lotus, lotus and sacred lotus. Chinese arrow-root may be tubers of *N. nucifera* (*N. speciosum*) (Figure 38). This is the root of the tropical aquatic plant that bears the lotus flower, which is commonly



Figure 38 Chinese arrowroot on sale in a Californian supermarket in November 2008. See colour plate section.

used in Buddhist temples. The plant appears to have originated in Southeast Asia and possibly Africa and has spread throughout the lowlands of southern Asia and into Australia. It was introduced into other tropical and subtropical regions and was an important plant of ancient Egypt and other eastern Mediterranean countries. It is now grown mainly as an ornamental in lakes and ponds but also as a source of food in many areas including India, Japan, Malaysia, China and Hawai'i. The fresh rhizomes are eaten after roasting; dried slices are fried as chips or used in curries. The rhizomes may also be pickled and quick frozen, but must be eaten young otherwise they are very tough and fibrous. They can be used as a source of a starch, similar to that of arrowroot. The capers are regarded as a delicacy and are eaten after the removal of the outer skin and the embryo, which is intensely bitter. They are eaten raw, roasted, boiled, candied or ground into flour (Kay 1987).

A perennial aquatic herb, rooting in mud, with a creeping white globulous rhizome that produces a single leaf and a single flower at intervals. Leaves have a wax coating and 60–90 cm in diameter on

long petioles often up to 2 m above the surface of the water. The flowers are solitary and 15–25 cm across in shades of pink, and are followed by a somewhat cone-shaped torus, 5–10 cm in diameter, with 10–30 carpels sunk into the upper surface that mature into ovoid edible achenes. The leaves and stems arise from thick spreading rhizomes that radiate out from the original plant and root forming new plants from buds on the rhizomes. The fleshy starchy rhizomes are up to 120 cm in length and 5–10 cm in diameter made up of section each about 7.5–15 cm long and weighing from about 150 g to 1.2 kg (Figure 39). They have a central air passage surrounded by several smaller ones and the flesh can vary in colour from white to pink or orange-buff. They are very fibrous and when freshly cut they exude a mucilaginous juice (Kay 1987).

The composition of the edible portion of the rhizomes have been quoted as energy 331 kJ 100 g⁻¹, water 78.3%, carbohydrate 19%, protein 1.4%, fat 0.2%, fibre 0.8%, ash 4%, calcium 4 mg 100 g⁻¹, iron 0.6 mg 100 g⁻¹, phosphorus 65 mg 100 g⁻¹, potassium 500 mg 100 g⁻¹, thiamine 0.14 mg 100 g⁻¹,



Figure 39 Water lily on sale in a Californian supermarket in November 2008. See colour plate section.

riboflavin 0.2 mg 100 g⁻¹, niacin 1 mg 100 g⁻¹ and ascorbic acid 4 mg 100 g⁻¹. The rhizomes are reported to contain approximately 2% asparagine. The leaves, carpels and rhizomes were reported to contain alkaloids. Nelumbine has been isolated from the petioles, pedicel and seed embryo, which acts as a cardiac poison. Roemerine, dehydroroemerine, nuciferine, dehydronuciferine, pronuciferine, nor-nuciferine, *N*-nornuciferine, armepavine, liriodene, *N*-methylcoclaurine, anonaine and dehydroanonaine have been extracted from the leaves (Kay 1987).

Harvesting and storage

The rhizomes mature to a suitable stage for eating in approximately 6–9 months, though if not harvested will continue growing until checked by competition. They are normally dug by hand after the ponds have been drained just before harvesting, but a mechanical harvesting system was being developed in Japan. Mineral powders are incorporated into some films used for packing lotus root (Industrial Material Research 1989, quoted by Abe 1990).

Diseases

In Japan, rhizome rots have caused a considerable reduction in lotus root production. Two microorganisms have been identified: *Bacillus nelumbii* and *Fusarium bulbigenum* Wr. *Nelumbicolum*. They have been associated with iron deficiency, especially on light sandy soils (Kay 1987).

Maca

Brassicaceae, Cruciferae

Lepidium meyenii Walpers, *L. peruvianum*. Other common names include Peruvian ginseng, maka, mace, maca-maca, maino, ayak chichira, ayuk willku and pepperweed. Maca is a perennial plant from the Andes mountains of Peru, Bolivia, Paraguay and Argentina at altitudes of 2000 to almost 4000 m. Maca Root was domesticated during the pre-Inca time around 3800 BCE, with primitive cultivars being found in archaeological sites dating back over 3500 years. It occurs at elevations above 3500 m and often reaching 4500 m. For the indigenous people the roots were also frequently traded with

communities at lower elevations. It is an important staple in the diets because it has the highest nutritional value of any food crop grown in the region where poor and rocky soil, low temperatures and high winds make the cultivation of other crops difficult (Johns 1981). The root is highly valued for food and properties linked to fertility and vitality and it has been claimed to have an effect on fertility, frigidity, sexual impotence and mental deficiency. It is eaten baked, dried, or added in juices, milk, porridge and jam. The roots are sometimes used as a flavouring agent for a local alcoholic beverage called aguardiente (Johns 1981, Kay 1987, Tello *et al.* 1992). It is a perennial herb propagated by seed, however, when cultivated it is treated as an annual. Its root system requires 7–9 months to become mature enough to harvest. The hypocotyls/roots look like a large radish, have a tangy, sweet taste and an aroma similar to that of butterscotch (Kay 1987).

Clément *et al.* (2009) found that its potentially bioactive components had no constant composition. The composition was influenced by differences among colour types but mainly by the effect of the site in which they had been grown. The four main cultivars of maca are black, purple, red and cream; none of these has been definitely proven to be a superior medicinal herb to any of the others (Kay 1987). Roots contain glucosinolates that are responsible for the pungent smell and taste and isothiocyanates. Fresh roots contain about 80% water. When dried for storage the analysis of roots shown that they had 10.4% water, 25–78% carbohydrates, 8.5% whole fibre, 2.2% lipids, 4.9% of ash and about 10.2–13.4% proteins. The protein content may vary depending on soil fertility and the variety. Minerals content included calcium 150–258, iron 15.4–16.6, copper 5.9, zinc 3.8, manganese 0.8, potassium 2050 and sodium 18.7 mg 100 g⁻¹ of dry matter (Dini *et al.* 1994, Quiros *et al.* 1996). Chacón de Popovici (1990, 1997) by proximate analysis of the dried roots reported that they had moisture 9.71 g, total proteins 17.99 g, fat 0.82 g, fibre 5.30 g, ash 3.49 g, carbohydrates 62.62 g, total nitrogen 2.87 g, non-protein nitrogen 1.55 g, pure protein 8.25 g, starch 37.86 g, soluble sugars 6.17 g and direct reducing soluble sugars 16.52 g 100 g⁻¹. Yuri Fruit (n.d.) gave the amino acids in mg concentration g⁻¹ protein as: glutamic acid 156.5, arginine 99.40, aspartic acid 91.70,

leucine 91.00, valine 79.30, glycine 68.30, alanine 63.10, phenylalanine 55.30, lysine 54.50, serine 50.40, isoleucine 47.40, threonine 33.10, tyrosine 30.60, methionine 28.00, HO-proline 26.00, histidine 21.90, sarcosine 0.70, proline -0.50, cysteine 0.05 and tryptophane 0.05. Vitamins included niacin 43.03, ascorbic acid 3.52, riboflavin 0.61 and thiamine 0.42. They also contained other chemicals and phytochemicals including benzyl and p-methoxybenzyl glucosinolates, saponins, steroids and/or tryptophanes, phenolic compounds, flavonoids and/or coumarins, tannins, glycosides, secondary aliphatic amines, tertiary amines; chlorophormic phase: alkaloids; methanolic phase: fructose and alkaloids.

Harvesting and storage

The crop takes 8–10 months to reach maturity and are usually harvested after frost has damaged the leaves; the plants are dug up by hand or spades, the leaves are removed and the roots cleaned and dried in the sun (Kay 1987). The dried root can be stored in a cool, dry place for several years (although after the 2nd year the flavour deteriorates) and is easily rehydrated by boiling in water until soft (Kay 1987).

Diseases

Tello *et al.* (1992) reported that fungal pathogens causing diseases present in the high Andes were *Fusarium gramineum* and *Rhizoctonia solani*.

Macadamia nuts

Proteaceae

Macadamia integrifolia Maiden. They are native to Australia and are produced there as well as in Hawai'i, Central and South Americas and parts of Africa. The edible kernel is enclosed in a thick, hard shell that, in turn, is enclosed in a husk that separates from the tree at about the time the seed is mature. The kernel is nearly spherical, consisting of joined equal-sized halves, i.e. cotyledons.

Harvesting and storage

Kernels are mature when oil accumulation is complete and shortly after this time, the nuts fall to the

ground and should be collected each month. Shaking may also be used (Cavaletto 2002). Cavaletto (2002) reported that they should be dehusked within 24 h of harvest, after which they should be dried. Freshly fallen nuts contain about 25% moisture in the kernel, although where collection is delayed they may have as little as 10–15% moisture. Drying should begin with ambient air, followed by a gradual increase in temperature up to 60 °C in the final stage of drying. Drying may be completed in shell to 1.5% kernel moisture or they can be partially dried in shell to about 5–6% kernel moisture, followed by cracking and finish drying of kernels alone to 1.5% moisture. It is important to protect the dried kernels from moisture and O₂ since exposure to moisture results in loss of crispness and shelf life. Moisture-proof packaging and vacuum packaging or nitrogen flushing is used. Prolonged exposure to O₂ results in rancidity. Cold storage is normally not necessary for short-term storage, but might be desirable for extended periods (Cavaletto 2002). SPLFS (2001) recommended storage of kernels at 0–5 °C and 0–0.5% O₂.

Malacca yam

Dioscoreaceae

Dioscorea atropurpurea Roxb. is also called Rangoon yam. Sturtevant (1892) wrote 'Siamese countries. The Malacca yam is cultivated in India and is known in Calcutta as the Rangoon yam. It is called in Burma myouknee and is cultivated. Now grown principally as an ornamental climber. It was observed in Japan by Thunberg (1784).'

Mauka

Nyctaginaceae

Mirabilis expansa Ruiz & Pavón. Other common names include tazo, miso, chagos, arricón, yuca Inca, yuca de la jalca, pega pega, arracacha de toro and camotillo. Its wild ancestors have been found in Bolivia, Ecuador, Peru and Colombia, and it is probably an ancient crop, which was perhaps first described in the 1960s in three separate locations in Bolivia, Ecuador and Peru. It is a low, compact plant grows up to 1 m in height. The thickened stems below ground are white, salmon coloured or yellow and are

commonly smooth and fleshy; about 5 cm in diameter and 50 cm long. The swelling process of the stems is the result of cambium activity creating irregular peripheral tissues around the external part of the stem. Towards the centre, several elliptical rows of isolated xylem vessels develop, but the basic tissue is parenchyma. Some varieties have mucus membranes that can irritate when eaten and they should be sun dried and boiled before eating to eliminate the irritating substance (Facciola 1990, Popenoe *et al.* 1989). These varieties, especially those from Bolivia, when exposed to the sun become sweet and are pleasant to eat and are boiled and eaten as a vegetable. Forms grown in Ecuador are not astringent. Roots can be used in sweet or savoury dishes (Popenoe *et al.* 1989). The cooking water makes an especially flavourful drink (Facciola 1990). Their protein, calcium and phosphorus contents are higher than other roots and tubers grown in the same agro-ecological area in the high Andes. This is an important advantage because the diet of people is frequently deficient in calcium and phosphorus and was an important root crop to the Incas. Analyses of roots grown in Bolivian had 7% protein, 2760 mg 100 g⁻¹ d.w. of calcium and 590 mg 100 g⁻¹ d.w. of phosphorus on a dry weight. Leaves contained 17% protein (Rea 1982). Analysis of three cultivars from Cajamarca in Peru had 4–5% protein and variable calcium content of 157–461 mg 100 g⁻¹ and phosphorus of 117 mg 100 g⁻¹ with is low sodium and iron. Other analyses give 87% carbohydrate and 7% protein for the swollen roots (Facciola 1990, Popenoe *et al.* 1989).

Mishqui

Solanaceae

Solanum muricatum Aiton. Other common names include pepino and tree melon. It is found in the lower altitudes of the Andes and probably originated in Peru. The edible portion is the fruit, which has a smooth yellow skin streaked with purple and is up to 15 cm long with pale yellow flesh. It can be eaten fresh and was said to have a sweet melon flavour with a hint of lemon and pineapple (Popenoe 1992). Citric acid and an approximately equal amount of malic acid and tartaric acids were present in all ripening stages (Huyskens-Keil *et al.* 2000). The seeds are also said to be edible.

Differences in maturity between clones of up to 20 days were found in the fruit growth period (Prohens and Nuez 2001), but generally harvest maturity is based on skin colour change from green to yellow. In an experiment fruits were harvested at the mature-green, colour break and ripe stages by Huyskens-Keil *et al.* (2000). They found that fruits at the colour break stage showed a better postharvest behaviour and reduced quality losses, specifically at a storage temperature of 5 °C. Refrigerated storage recommendations are as follows:

- 7–10 °C and 90% r.h. for 4–6 weeks (Snowdon 1990).
- 4.4 °C and 85–90% r.h. for 30 days (SeaLand 1991).
- 5 °C and 98% r.h. for up to 21 days (Waskar *et al.* 1999).
- 5 °C for up to 21 days (Huyskens-Keil *et al.* 2000).

Controlled atmospheres resulted in higher quality fruit after storage compared to storage in air and short bursts of high CO₂ concentrations improved skin firmness and colour intensity (Waskar *et al.* 1999).

Ripening

Glucose and fructose contents declined during ripening at 18 °C, whereas sucrose content increased significantly, leading to a higher ratio of disaccharides to monosaccharides in ripe fruits than in younger fruits. During ripening, the sugar:acid ratio increased until the fruits reached the colour break stage, but declined thereafter, with the ratio being 16:1 and 13:1 in colour break and ripe fruits, respectively (Huyskens-Keil *et al.* 2000). Prohens and Nuez (2001) studied different clones in response to Ethephon sprays (0, 500 or 2000 mg L⁻¹). Some clones did not respond to the sprays, while in others the ripening period was shortened by more than 60%. In general, the effect of Ethephon was greater in the clones with a longer ripening period. The effects of Ethephon on fruit quality characteristics were not significant in the majority of clones, although in five clones Ethephon resulted in skin degreening, a higher firmness and lower soluble solid content after storage compared to those not treatment. On the other hand, Ethephon sprays did not affect either the postharvest behaviour or the sensitivity of fruit to bruising.

Mung beans

Fabaceae, Leguminosae

Vigna radiata (L.) Wilczek synonymous with *Phaseolus aureus* Roxb. *P. radiatus* L. also called green gram. They are native to tropical areas of Asia and are widely grown there. It is an annual erect sub-shrub up to about 90 cm tall. There are mesophytic and xerophytic forms with the latter producing a deep tap root with obliquely downward growing lateral roots. When grown for seeds they are harvested when the pods begin to darken. Pods mature at different times and in India they are harvested by hand every 5 or 6 days. Some cultivars have been selected where the pods mature more evenly and in the United States they are harvested by machines. The mature seeds can be boiled or ground into flour for use in bakery products and fried snack foods and a noodle-like product called long rice. In China they are commonly grown for sprouting and are consumed as a vegetable. The seeds are soaked in water then placed in vats where they are kept in the dark at about 24 °C and sprinkled with water to maintain 60–70% r.h. until the spouts are 12–16 mm long, which takes about 4 or 5 days. They have a very short shelf life (Kay 1979).

Oca

Oxalidaceae

Oxalis tuberosa Molina. Other common names include apio blanco, cu, huisisai, ibias, macach miquichi, papa extranjera and quiba. Oca grows in the high Andes and is limited to southern Colombia, Bolivia, Ecuador, Peru and northern Chile, between 4°N and 17°S at an altitude of 2800–4500 m. It may be one of the oldest Andean crops. Tubers have been found in early tombs on the coast, hundreds of kilometres from its native highland habitat. Although wild relatives exist throughout much of South America, the ancestral plant is unknown (King and Gershoff 1987). Native Amerindian communities of Bolivia and southern Peru regard Oca as second in importance to the potato among root and tuber crops. Oca tubers are usually baked or cooked in stews, although rural children sometimes eat them raw.

It is a compact, perennial, tuberous herb, usually up to 30 cm high, with cylindrical, succulent stems that

vary in colour from yellow and green to a purplish red. In long days, the stolons grow as above-ground stems. As days shorten, the stolons penetrate the soil and swell to form tubers. The edible portion is the tuber, which has a smooth skin bearing scales that cover long deep eyes. They are small, 3–20 cm long, and are often turbinate in shape although shape and colour vary considerably between cultivars but are commonly white, yellow or red (Kay 1987, Purseglove 1968). Cultivars are sometimes grouped into sweet and bitter. The latter contain calcium oxalate crystals, an anti-nutritional factor. High levels of oxalate were found by Hermann and Erazo (2001) ranging from 306 to 539 mg 100 g⁻¹ in edible matter of freshly harvested tubers of the native Colombian cultivars ECU-1018, ECU-1025, CA-5054, MU-028 and HN-1146. The young shoots and leaves can be used in salads or boiled like spinach. It originated in the high Andes of South America.

Oca contains oxalates, but cooking by boiling or steaming is recommended for minimizing oxalate levels, while baking appeared to increase oxalate content (Albihn and Savage 2001). Yellow oca contains carotenoids and the red skinned cultivars also contain anthocyanins. Flores *et al.* (2002) reported that in terms of nutrition oca compare favourably with potatoes. Major food components include some vitamin A, vitamin B6 and fibre, and small amounts of riboflavin, thiamine and potassium (Hedges and Lister 2006). In a study of four Andean root crops Campos *et al.* (2006) found that the content of bioactive compounds was high and variable between crops and within the genotypes studied. The antioxidant capacity within the four crops studied varied from 483 to 9800 µg trolox equiv. g⁻¹. Phenolics ranged from 0.41 to 3.37 mg chlorogenic acid equiv. g⁻¹, anthocyanins ranged from 0.08 to 2.05 mg cyanidin 3-glucoside g⁻¹ and carotenoids ranged from 1 to 25 µg β-carotene g⁻¹. The overall average moisture content of the 14 oca genotypes supplied by the International Potato Center was 83 ± 1.9%. The most important sugars were sucrose and glucose; there are also traces of raffinose and stachyose. Protein accounted for about 1% of fresh matter (Gross *et al.* 1989, Kays *et al.* 1979), but the quality was low (Gross *et al.* 1989). Oca provides a good source of vitamin C (38 mg 100 g⁻¹) (Collazos *et al.* 1984), potassium and iron (Kays *et al.* 1979). Work in New Zealand revealed high levels of soluble oxalate in

oca, ranging from 92 to 221 mg 100 g⁻¹ edible matter (Ross *et al.* 1999). Dry matter and physically extractable starch accounted for 10.4–14.3% and 5.2–9.2% of freshly harvested edible matter, respectively. Total sugars comprised 2.1–3.6% and total organic acids amounted to 2.6–3.4% of fresh matter. Of the total sugars in freshly harvested tubers, about half was sucrose and about a quarter each of fructose and glucose. Among the organic acids, glutarate and malate were most abundant and tartarate least. There were notable differences between accessions, especially regarding the content of starch, total sugars and single acids. Accessions ECU-1025 and CA-5054, which had the highest dry matter and starch content, were also high in total sugars, but had average acidity. HN-1146 had almost twice the oxalate content of CA-5054, but its total acid content was only 11% higher. This suggests the existence of considerable variation in the acid profiles of different oca cultivars. However, the statistical significance of these results cannot be determined because only one pooled sample was studied.

Harvesting

In Colombia they mature some 8 months after planting and are dug by hand and generally, especially those of bitter varieties, are left for several days in the sun to eliminate most of the bitterness due to calcium oxalate (Kay 1987).

Curing

After harvesting, oca tubers destined for immediate consumption are traditionally laid out in the sun for a week or two. This is referred to as *sunning*, or *soleado*, and enhances sweetness and improves culinary quality. It is also thought necessary for the bitter cultivars to reduce calcium oxalate levels (Kay 1987). In an experiment Hermann and Erazo (2001) exposed harvested oca to direct sunlight for several days. This treatment increased the proportions of dry matter, soluble solids, and sugars (mainly sucrose), reduced oxalate levels in dry matter by an average of 26% and decreased total acids, due mainly to a large reduction in malate and glutarate. Cortes (1978) described a sunning experiment near Quito, Ecuador. Tubers were placed on aluminium foil in a greenhouse the day after harvest and left for 10 days.

They were thus exposed to full sunlight and protected from rain. The tuber temperatures varied between 7–10 °C at night and 35 °C in the early afternoon.

In comparison with freshly harvested tubers, sunning increased dry matter content through water evaporation, soluble solids and total sugars, but sharply decreased levels of starch and organic acids. For example, sugar levels almost doubled in CA-5054 and HN-1146, while total acids in ECU-1025 was reduced to less than a third of the level in freshly harvested material. The decrease in acids was due to large reductions in glutarate and malate, typically to less than 30% of the values of freshly harvested oca, whereas oxalate, succinate and tartarate showed a slight overall increase. This increase was probably due to a concentration effect resulting from dehydration of the sunned tubers. In contrast to fresh matter, dry matter analysis showed a reduction in levels of oxalate and succinate in all five accessions, whereas tartarate was reduced in three accessions. Similar tendencies were seen for sugars. Fructose and glucose concentrations were generally higher in the edible matter of sunned tubers compared with freshly harvested material, whereas analysis of dry matter showed that both sugars tended to diminish in sunned tubers. Sucrose accounted for most of the increase in total sugars after sunning, in both edible matter and dry matter (Hermann and Erazo 2001).

Storage

In South America they are usually preserved by sun drying when they have a sort of dried fig flavour. At 21 °C the fresh tubers can be kept for 12 weeks. The limiting factors were sprouting and deterioration in flavour. Refrigerated storage recommendations were 4 °C for 20 weeks (Kay 1987).

Okra

Malvaceae

Abelmoschus esculentus (L.) Moench is synonymous with *Hibiscus esculentus* L. Other common names include gumbo and lady's finger. It originated in tropical Africa but has spread throughout the world where it grows well in the lowland tropics (Purseglove 1972). Cultivars suitable for temperate areas such as the Iberian Peninsula have been developed. It is an



Figure 40 Okra from Jordan on sale in an open market in Bedford in Britain in July 2009. See colour plate section.

annual plant that grows up to about $1\frac{1}{2}$ m high. The fruit, which is the edible portion, is a beaked capsule with longitudinal furrows that split, when fully mature, to release the seeds (Figure 40). There are many cultivars ranging from those where the skin is completely smooth to those that are hirsute or spiny. The chemical content which was given by USDA Nutrient Database (2012a) is presented in Table 81. Total world production in 2010 was estimated by FAO (2012) as 6,942,251 tonnes.

Harvesting and handling

They are harvested while still immature, tender, crisp and without fibre. In the tropics this is usually 4–5 days after flowering, and harvesting should be every 1–2 days. They are commonly harvested by hand and placed into a suitable container. In the Sudan polyethylene film liners were used in field boxes to reduce the rate of dehydration. However, if they were kept too long inside plastic film condensation occurred on the surface causing water spotting. This is a black spotting on the skin that makes them

Table 81 The composition of okra fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	90.17 g	Thiamine	0.200 mg
Energy	31 kcal	Riboflavin	0.060 mg
Protein	2.00 g	Niacin	1.000 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.215 mg
Carbohydrate, by difference	7.03 g	Folate	88 µg_DFE
Total dietary fibre	3.2 g	Vitamin B-12	0.00 µg
Sugars, total	1.20 g	Vitamin A	19 µg_RAE
Calcium	81 mg	Vitamin A	375 IU
Iron	0.80 mg	Vitamin E (α-tocopherol)	0.36 mg
Magnesium	57 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	63 mg	Vitamin D	0 IU
Potassium	303 mg	Vitamin K (phylloquinone)	53.0 µg
Sodium	8 mg	Fatty acids, total saturated	0.026 g
Zinc	0.60 mg	Fatty acids, total monounsaturated	0.017 g
Total ascorbic acid	21.1 mg	Fatty acids, total polyunsaturated	0.027 g

unsightly (Thompson *et al.* 1973c). Rapid cooling helped to maintain their freshness, but top icing was reported to cause water spotting (Lutz and Hardenburg 1968). Forced air pre-cooling with high humidity air would cool them quickly without causing desiccation. Some growers use hydrocooling.

Postharvest physiology

Baxter and Waters (1986) reported that they produced only small amounts of ethylene at 0.5 µl kg⁻¹ h⁻¹ during storage but small concentrations of ethylene in the storage environment can lead to chlorophyll breakdown and yellowing. Okra pods exposed to greater than 1 µl L⁻¹ ethylene for 3 or more days showed yellowing (Perkins-Veazie 2002). She also gave the respiration rate in Table 82.

Storage

Weight loss is a major cause of reducing storage life since it results in them losing their crispness. At room temperature of 20 °C and 60% r.h. they could be kept for 1–2 days (Mercantilia 1989). Chilling injury can occur in storage at 7.2 °C as pitting, surface discolouration, water-soaked or exuding lesions, decay

Table 82 Respiration rates of okra fruit at different temperatures (source: adapted from Perkins-Veazie 2002)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
2–3	10–32
4–5	21–59
10	86–95
15–16	138–153
20–21	248–274
25–27	328–362

and they may turn a brown to olive green colour (Lutz and Hardenburg 1968, Perkins-Veazie 2002). Suzuki and Okabayashi (2001) reported chilling injury in storage at 6 °C but not at 10 °C. Perkins-Veazie (2002) reported that exposure to 2 °C for just 2 days can cause chilling injury. When pods were stored for 7 days at 2 or 5 °C chilling injury symptoms occurred within 24 h when they were transferred to 20 °C (Perkins-Veazie 2002). Refrigerated storage recommendations were:

- 8.9 °C and 90% r.h. for 2 weeks with 6.8% loss (Pantastico 1975)
- 7.2–10 °C and 90–95% r.h. for 7–10 days (Lutz and Hardenburg 1968)
- 7–10 °C and 95% r.h. for up to 10 days with up to 10% weight loss (Tindall 1983)
- 10 °C and 90% r.h. for 7–10 days (Mercantilia 1989)
- 7–10 °C and 95–100% r.h. for 1–2 weeks (Snowdon 1991)
- 10 °C and 90–95% r.h. for 7–10 days (SeaLand 1991).

Controlled atmosphere storage

Ogata *et al.* (1975) stored okra at 1 °C in air or 3% O₂ + 3, 10 or 20% CO₂ or at 12 °C in air or 3% O₂ + 3% CO₂. At 1 °C there were no effects of any of the controlled atmosphere treatments, but at 12 °C the controlled atmosphere storage resulted in lower ascorbic acid retention but it improved the keeping quality. Anandaswamy (1963) found that in storage in 10–12% CO₂ off-flavour may be produced. Other recommended conditions are:

- 7.2 °C with 5–10% CO₂ kept them in good condition, but with levels of 10–12% CO₂ off-flavours may be produced (Pantastico 1975).

- 8–10 °C with 0% CO₂ and 3–5% O₂ which had a fair effect but was of no commercial use, but CO₂ at 5–10% was beneficial at 5–8 °C (Kader 1985).
- 5–8 °C with 5–10% CO₂ or 3–5% O₂ + 0% CO₂ (Baxter and Waters 1986).
- 7–12 °C with 4–10% CO₂ and 21% O₂ which had only a slight effect (Saltveit 1989).
- 7–10 °C with 5–10% CO₂ lengthened their shelf life by about a week compared to air storage at the same temperature (Hardenburg *et al.* 1990).
- 10 °C and 90–95% r.h. with 0% CO₂ with 3–5% O₂ (SeaLand 1991).

Modified atmosphere packaging

Hardenburg *et al.* (1990) reported that storage in 5–10% CO₂ lengthened their shelf life by about a week. Finger *et al.* (2008) stored the Brazilian cultivar Amarelinho at 25, 10 or 5 °C wrapped in PVC over a polystyrene tray or left not wrapped. The development of chilling symptoms (surface pitting) occurred at 5 °C but was delayed in those covered with PVC film. Those stored at 25 °C lost weight rapidly and became wilted especially those not wrapped, therefore 10 °C covered in PVC was the best treatment. Mota *et al.* (2006) also found that PVC over wraps were efficient in reducing weight loss and in retaining the vitamin C contents and reducing browning during storage. Babarinde and Fabunmi (2009) found that the ascorbic acid was better retained in okra in LDPE bags compared to those not wrapped or in 15 ± 2 °C compared to those in storage in ambient conditions of 28 ± 2 °C. Both 15 °C storage and storage in LDPE bags extended their marketable life. Rotting was observed after 12 days of storage and there was an overall decrease during that time in pH from 6.7 to 5.5.

Diseases

Chladosporium, grey mould (*Botrytis cinerea*), mildew, yeasts, *Rhizopus stolonifer*, *R. solani*, *Psuedomonas* pv *syringae* were associated with postharvest diseases (Snowdon 1991). Suzuki and Okabayashi (2001) found that the occurrence of lesions caused by *Alternaria alternata* was severe during storage at 20 °C or higher, while they were slight during storage at 10 °C, however, later the

lesions increased rapidly. Also they found that the lesions increased when the relative humidity was above 95%, while the occurrence of the disease declined below 90% r.h.

Onions

Alliaceae, Liliaceae

Allium cepa L. *A. cepa* can be divided into several groups including *A. cepa* L. var. *cepa*, which is the bulb onion, *A. cepa* L. var. *proliferum* Targioni-Tozzetti called the tree onion and *A. cepa* L. var. *aggregatum* G. Don, which includes shallots, ever-ready onion and potato onion and is synonymous with *A. ascalonicum*. The plant is a biennial, and the edible part is the mature bulb. The bulb is produced in the first year of growth, if it is not harvested it becomes dormant and then regrows in the following season when it flowers and produces seed. Bulbs will freeze at about -1.3 to -0.9°C (Wright 1942). The chemical content was given by USDA Nutrient Database (2012a) in Table 83. Total world production of dry onions in 2010 was estimated by FAO (2012) as 78,534,876 tonnes.

Table 83 The composition of onion bulbs for 100 g^{-1} fresh weight (source: adapted from USDA 2012a)

Water	89.11 g	Thiamine	0.046 mg
Energy	40 kcal	Riboflavin	0.027 mg
Protein	1.10 g	Niacin	0.116 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.120 mg
Carbohydrate, by difference	9.34 g	Folate	19 $\mu\text{g_DFE}$
Total dietary fibre	1.7 g	Vitamin B-12	0.00 μg
Sugars, total	4.24 g	Vitamin A	0 $\mu\text{g_RAE}$
Calcium	23 mg	Vitamin A	2 IU
Iron	0.21 mg	Vitamin E	0.02 mg
		(α -tocopherol)	
Magnesium	10 mg	Vitamin D (D2 + D3)	0.0 μg
Phosphorus	29 mg	Vitamin D	0 IU
Potassium	146 mg	Vitamin K	0.4 μg
		(phyloquinone)	
Sodium	4 mg	Fatty acids, total saturated	0.042 g
Zinc	0.17 mg	Fatty acids, total monounsaturated	0.013 g
Total ascorbic acid	7.4 mg	Fatty acids, total polyunsaturated	0.017 g

Harvesting

Bulb onions, which are to be stored, should be allowed to mature fully before harvest. This is judged to when the leaves bend just above the top of the bulb and fall over. In practice the farmer calculates the percentage of bulbs that have fallen over in a field by doing sample counts, and when it reaches say 70% then the whole crop will be harvested. The tops may be cut-off mechanically before harvesting. With some machines the crop may be left on the soil surface after harvesting; in others they may be lifted and loaded into a trailer for direct transport to the store or pack-house (Figure 41). Some harvesters have the facility to top and pack the crop directly in the field into whole-sale or retail packs.

In a study by Maw *et al.* (1997) over three seasons, bulbs of the cultivar Granex 33 were harvested at three stages of maturity (early, optimum or late), cured for 24, 48 or 72 h in heated air at $35-38^{\circ}\text{C}$ and stored at about 24°C in either high or low humidity. Of all treatments, harvest maturity had the greatest influence upon storability. Early harvested bulbs exhibited the best storability. Storability was prolonged following 48 h of curing and was enhanced by



Figure 41 Mechanical harvesting of onions in Britain.

low humidity. Storability was not enhanced by curing for greater than 24 h for late or greater than 48 h for optimally harvested bulbs. For early harvested bulbs, curing for as long as 72 h enhanced storability. Early harvested bulbs had not reached their highest quality or their maximum yield, so it was concluded that the optimal harvest maturity would have to be a compromise among yield, quality and storability. In New Zealand bulbs lifted at 60–80% top-down, field-cured, and the foliage removed after curing, was the simplest method and best compromise to ensure postharvest quality and successful storage. Onions that were lifted 3 weeks after 50% top-down and topped before curing had the greatest incidence of rots in store. Increasing harvest maturity not only increased their skin colour but also increased the number of loose skins (Wright *et al.* 2001).

Harvest maturity can affect physiological disorders. In trials carried out in South east Norway late harvesting at about 100% leaf fall-over, high drying temperature 30 °C and a long drying duration produced the highest incidence of the physiological disorder translucent scales, the highest internal CO₂ levels and the lowest O₂ levels. Late harvesting and prolonged field curing gave the highest occurrence of leathery scales (Solberg and Dragland 1998).

Stow (1976) found an increase in the concentration of inhibitors in the leaves of onions approaching maturity and showed that defoliation at this stage shortened dormancy.

Handling and packaging

If bulbs were dropped on to a hard surface they could be damaged even if the fall was as little as 30 cm (Thompson *et al.* 1972a, 1972b). Bulbs dropped from 105 cm reached a high respiration rate of 26 mg kg⁻¹ h⁻¹ CO₂, which gradually decreased and after 12 days the respiration rates seemed to reach an approximately constant level. However, after 16 days a further decrease was observed and after 19 days the values for the sample with 105 cm drop height and those not dropped reached the same final value of about 8 mg kg⁻¹ h⁻¹ CO₂ (Herold *et al.* 1998). Magnetic resonance imaging has been used to obtain images of onions in order to detect bruises during postharvest grading (Chen *et al.* 1989). Extruded plastic nets are commonly used for onions, where two strands cross they are welded together. They are

Table 84 Effects of number and size of perforation in 1.36 kg, 37.5 µm polyethylene film bags of Yellow Globe onions on the relative humidity in the bags, rooting of the bulbs and weight loss after 14 days at 24 °C (source: adapted from Hardenburg 1955)

Number of perforations	Perforation size (mm)	Percentage of r.h. in bag	Percentage of bulbs rooted	Percentage of weight loss
0	–	98	71	0.5
36	1.6	88	59	0.7
40	3.2	84	40	1.4
8	6.4	–	24	1.8
16	6.4	54	17	2.5
32	6.4	51	4	2.5
0 ^a	–	54	0	3.4

^aKraft paper with film window.

usually made in a long tube and cut to the required size and the bottom stitched to form a bag. Packing bulbs in plastic film is uncommon because the high humidity inside the bags can cause rotting and root growth (Table 84).

Curing and drying

Bulbs are normally dried before storage. This does not involve drying the crop to an even, low moisture content as in dehydration, but only drying the outer layers. The object of drying the outer layers of skin and the neck of the bulb is to provide a surface barrier to water loss and microbial infection. This process is sometimes referred to as *curing*; but since no cell regeneration or wound healing occurs it is clearer to refer to it as drying. Traditionally drying of onions has been carried out in the field and called windrowing. This involves pulling the bulbs from the ground when they are mature and laying them on their sides to dry for 1 or 2 weeks. In wet weather the bulbs can take a long time to dry and they may have increased levels of rots in subsequent storage. In hot climates the bulbs may be damaged by direct exposure to the sun. In such circumstances the bulbs should be windrowed in such a way that the drying leaves of one bulb covers the adjacent bulb to reduce the exposed surface. If the soil is wet then the side of the bulb in contact may develop brown stains which can adversely affect the appearance and the value of the bulb.

Because of these problems many bulbs are not now windrowed. Instead they are taken straight from the field and dried in the store. This drying is achieved

by constantly passing air across the surface of the bulbs at about 30 °C and 70% r.h. If the humidity is too high drying is delayed and the levels of fungal disease can increase: if it is too low the skins of the bulbs can split which reduces their value and can increase subsequent losses. Onions develop the best skin colour at temperatures of 25–32 °C. Drying may take 7–10 days and is judged to be complete when the necks of the bulbs have dried out and are tight and the skins rustle when held in the hand.

Downes *et al.* (2009) exposed the cultivars Sherpa, Wellington and Red Baron at 20, 24 or 28 °C, respectively, for 6 weeks and then stored them for 7 months at 1 ± 0.5 °C. The brown cultivars Sherpa and Wellington were darker immediately after being exposed to 28 °C compared to those exposed to 20 °C but there was no effect on Red Baron when exposed to 28 °C compared to 20 °C. Quercetin glucoside and anthocyanin concentrations in the skin of Red Baron immediately after curing were higher in those exposed to 20 °C than at the other temperatures. Stow (1976) found a rise in growth inhibitory substances in the leaves of onions approaching maturity. The onset of dormancy was related to translocation of growth inhibitory substances from the leaves to the bulbs and defoliation at this stage could shorten their dormancy.

Sprout suppression

In India Noor and Izhar (1998) reported that sprouting started in most cultivars after 4 weeks storage under ambient conditions of 35 °C with 70% r.h. but some cultivars sprouted later than 4 weeks. Respiration rate and therefore sprouting of bulbs decreased with increasing temperature over the range 15–25 °C (Karmarkar and Joshi 1941). Storage at 25–30 °C was shown to reduce sprouting and root growth compared to storage at 10 to 20 °C but weight loss was high (Thompson 1982).

Application of chemical sprout suppressants in storage does not work for onions because the meristematic region, where sprouting occurs, is deep inside the bulb and the chemicals do not normally penetrate so far into the tissue. It is therefore achieved by preharvest application of maleic hydrazide. MH is applied to the leaves of the crop some 2 weeks before harvesting usually when bulbs are mature and 50% of tops have bent over but still have at least five

green leaves so that the chemical can be absorbed and translocated to the middle of the bulb into the meristematic tissue (Thompson *et al.* 1972a, 1972b). MH should be applied according to the manufacturer's instructions but 2500 µl L⁻¹ sprayed on the crop shortly before the leaves die down was recommended by Tindall (1983).

Other methods of sprout control in onions include salicylic acid and irradiation. Noor and Izhar (1998) found that dipping the bulbs in 600, 800 or 1000 µl L⁻¹ salicylic acid before storage reduced sprouting and rotting. Sprout suppression can also be achieved by irradiating the bulbs with doses of 20–30 Gy. This level completely prevent sprouting if applied as soon as possible after harvest (Chachin and Ogata 1971), but irradiation is not permitted in all countries and where it is there is often consumer resistance to its use.

Alternatives to the use of postharvest chemicals are becoming increasingly important and the use of CA is a possible alternative to MH. CA stores are being constructed for onions and Yamashita *et al.* (2009) reported that a CA store with a total capacity of 9300 tonnes was constructed in Japan for onions. Previously Isenberg (1979) concluded that CA storage is an alternative to the use of sprout suppression in onions, but stressed the need for further testing of the optimum condition of O₂ and CO₂ required for individual cultivars. Adamicki and Kepka (1974) also quoted work where onions stored in an atmosphere with 5–15% CO₂ at room temperature showed a decrease in the percentage of bulbs that sprouted. They also reported that bulbs of cultivar Wolska stored for 163 or 226 days in 5% CO₂ + 3% O₂ and then transferred to 20 °C sprouted about 10 days later than those transferred from air storage. There is evidence that CA storage can have residual effects after they have been removed from store. Bulbs of cultivar Wolska stored for 163 or 226 days in 5% CO₂ + 3% O₂ and then transferred to 20 °C sprouted about 10 days later than those transferred from air storage (Adamicki and Kepka 1974). Yamashita *et al.* (2009) reported that storage at 1 °C and 80% r.h. in 1% O₂ + 1% CO₂ for up to 196 days inhibited sprouting and root growth. In 10% CO₂ + 3% O₂ at 4.4 °C Chawan and Pflug (1968) found that bulbs showed no sprouting after 34 weeks, while bulbs stored in air had 10% sprouting for Dowing Yellow Globe and 15% for abundance. In a detailed study of 15 different cultivars and various

CA combinations Gadalla (1997) found that all the cultivars stored in 10% CO₂ for 6 months or more had internal spoilage (but not after 3 months) with more spoilage when 10% CO₂ was combined with 3 or 5% O₂. All CA combinations, 1, 3 or 5% O₂ + 0 or 5% CO₂, reduced sprouting but those combinations that included 5% CO₂ were the most effective. Also the residual effects of CA storage were still effective after 2 weeks at 20 °C. No external root growth was detected when bulbs were stored in 1% O₂ compared to 100% for the bulbs in air. There was also a general trend to increased rooting with increased O₂ over the range 1–5%. Bulbs stored in 5% CO₂ had less rooting than those stored in 0% CO₂. Both these latter effects varied between cultivars. Most of the cultivars stored in 1% O₂ + 5% CO₂ and some cultivars stored in 3% O₂ + 5% CO₂ were considered marketable after 9 months of storage. He also found that CA storage was most effective when applied directly after curing, but a delay of 1 month was almost as good. It was therefore concluded that with a suitable cultivar and early application of CA it is technically possible to store onions at 0 °C for 9 months without chemical sprout suppressants. Sitton *et al.* (1997) found bulbs stored in 0.5–0.7% O₂ in cold storage sprouted more quickly when removed to 20 °C compared to those stored in O₂ levels of greater than 0.7%.

1-MCP

Greater concentrations of sucrose, glucose and fructose and better retention of dry matter were found in 1-MCP-treated bulbs of the cultivar SS1 stored at 12 °C as compared with non-treated bulbs (Chope *et al.* 2007). During storage at 18 °C exogenous ethylene suppressed sprout growth in the cultivar Copra of both dormant and already sprouting bulbs by inhibiting leaf blade elongation, but treatment of dormant bulbs with 1-MCP resulted in premature sprouting. The dormancy breaking effect of 1-MCP indicates a regulatory role of endogenous ethylene in onion bulb dormancy (Bufler 2009). In contrast Chope *et al.* (2007) reported that sprout growth was reduced in bulbs treated with 1 µl L⁻¹ 1-MCP for 24 h at 20 °C and stored at 4 or 12 °C, but not when they were stored at 20 °C. Downes *et al.* (2010) reported that bulbs of the cultivars Sherpa and Wellington were 'cured' at 28 °C for 6 weeks and treated with a single dose of 10 µl L⁻¹ ethylene or 1 µl L⁻¹ 1-MCP

for 24 h at 20 °C before and after curing. Together with non-treated bulbs they were stored for 38 weeks at 0–1 °C. Sprout growth was generally reduced in Sherpa treated with ethylene or with 1-MCP, but sprout growth of Wellington, which had a thicker skin, was not affected by any treatment. The respiration rate of both cultivars increased immediately after being treated with ethylene but to a lesser extent or not at all when treated with 1-MCP. It appears that inhibition of sprout growth can be achieved using with a 24-h exposure to ethylene or 1-MCP. However, skin thickness or permeability, cultivar and curing may affect ethylene or 1-MCP influx and therefore efficacy of sprout suppressant action.

Storage structures

A windbreak was a traditional way of storing onions in Britain and farmers claimed that they could be stored in this way for up to 6 months. Windbreaks are constructed by driving wooden stakes into the ground in two parallel rows about a metre apart. The stakes should be slightly sloping outwards and should be about 2 m high. A wooden platform is built between the stakes about 30 cm from the ground, often made from up turned wooden boxes. Chicken wire is fixed between the stakes and across the two ends of the windbreak. The bulbs are then loaded into the cage, covered with 15–20 cm on straw. On top of the straw a polyethylene film sheet of about 125 µm thick is placed and weighted down with stones to protect it from the rain (Figure 42). The windbreak should be cited with its longer axis at right angles to the prevailing wind.

In Britain cellars below houses were used for storing onions during the winter. The bulbs were usually spread out thinly on shelves to ensure good air circulation. In the Sudan onions are stored in palm leaf barns called rakubas in Arabic. The bulbs are stacked on bamboo a platform inside the structure to a maximum depth of about a metre. The nature of the structure allows good air circulation from the prevailing wind while protecting them from rain and direct sunlight. In many countries bulbs harvested with their tops still attached can be plaited into bunches and suspended from hooks.

In a study of night-ventilated storage, Skultab and Thompson (1992) showed that onions could be maintained at an even temperature very close to the



Figure 42 A traditional East Anglian windbreak onion store in the United Kingdom.

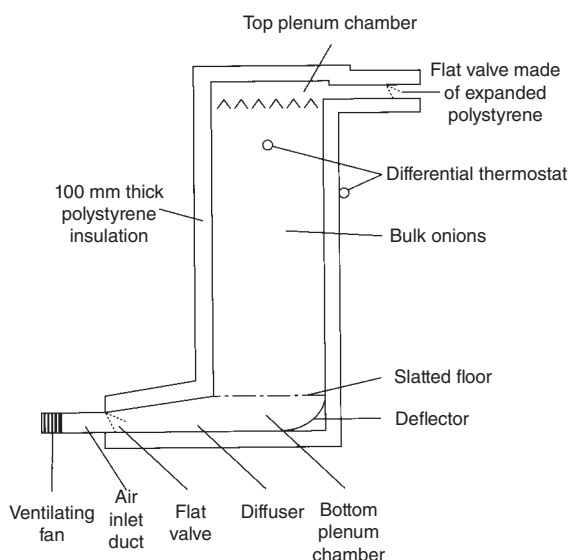


Figure 43 Diagram of a night ventilated onion store. (Source: Skultab and Thompson 1992.)

minimum night temperature. The design that was used is shown in Figure 43. A time switch can also be used which would be set to, for example, switch the fan on for 2 h each day between 5.0 and 7.0 am. An onion store was built and tested in the Sudan which was similar to that described above (Silvis and Thompson 1974). Losses were high but lower than those encountered using the traditional method of onion storage in the Sudan (Table 85).

Most onions are now stored in refrigerated stores usually in bulk stores (Figure 44) where they are

Table 85 Comparative storage losses of onion bulbs in a simple straw cottage (rakuba) and a night ventilated store during 6 months of storage at an average of 36.1 °C and 42% r.h. for the rakuba and 33.1 °C and 60% r.h. for the night ventilated store (source: adapted from Silvis and Thompson 1974)

Storage method	Sound by weight (%)	Rotting (%)	Sprouting (%)
Rakuba	43	22	7
Night ventilated	58	18	4



Figure 44 Bulk onion store in the process of being loaded in the United Kingdom.

harvested into trailers in the field and loaded directly onto the floor of the store. Warm air is blown through the bulk until they have been fully dried and then cold air is passed through them. They may also be stored in pallet boxes that are stacked in the refrigerated store. In some cases they are stored in bags but this can lead to high losses since the circulating air can pass around the bags rather than through them.

Postharvest physiology

Exposure of onions to ethylene gave them a milder flavour (Weichmann 1978). Inaba *et al.* (1989) found that there was an increased respiration rate of bulbs in response to ethylene at 100 µl L⁻¹ for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Ethylene production is very low, at <0.1 µl kg⁻¹ h⁻¹ at 20 °C and sensitivity to ethylene is also low, but concentrations greater than 1500–2000 µl L⁻¹ were reported to encourage sprouting of bulbs (Suslow and Cantwell 1998a). Low O₂

Table 86 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Bedfordshire Champion onions (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	3	5	7	7	8
In 3% O ₂	2	–	4	–	4

levels in storage reduced the respiration rate of bulbs at all temperatures studied (Table 86).

Storage temperature and humidity

At room temperature of 20 °C and 75–85% r.h. bulbs could be kept for about 25 days (Mercantilia 1989). Humidity of 70–75% r.h. should be maintained during storage with regular ventilation. Bulk storage height should not exceed 3 m to prevent compression damage to the lower bulbs, or they should be stored in boxes. Where the downward force on the crop is above a threshold level it can be bruised. This damage may also be a function of time, especially where the pressure is close to the threshold value. In boxes it may be as a result of overfilling them and then stacking the boxes so that the crop in the lower boxes supports the weight of the ones above. Storage recommendations were as follows:

- 0 °C and 70–75% r.h. (Wardlaw 1937);
- –3 °C and 85–90% r.h. for 5–6 months (Wardlaw 1937);
- –0.6 °C and 78–81% r.h. for 6–7 months (Wardlaw 1937);
- –3 to 0 °C and 70–75% r.h. for 6 months (Anonymous 1967);
- 0 °C and 75–85% for 6 months (Shipway 1968);
- 0 °C and 70–75% r.h. for 20–24 weeks with 16.3% loss for red onions (Pantastico 1975);
- 1.1 °C and 70–75% r.h. for 16–20 weeks with 14.2% loss for white onions (Pantastico 1975);
- 0 °C and 70–75% r.h. or 90–95% r.h. for up to 120 days (Tindall 1983);
- 30–35 °C and 75–85% r.h. (Tindall 1983);
- 0 °C and 65–70% r.h. for 6–8 months for Globe and 1–2 months for Bermuda (Hardenburg *et al.* 1990);
- –2 °C and 75–85% r.h. for 300 days (Mercantilia 1989);
- 0 °C for 230 days (Mercantilia 1989);

- 4 °C for 170 days (Mercantilia 1989);
- 8 °C for 120 days (Mercantilia 1989);
- 12 °C for about 90 days (Mercantilia 1989);
- –1 to 0 °C and 70–80% r.h. for 6–8 months (Snowdon 1991);
- 0 °C and 65–75% r.h. (SeaLand 1991).

Controlled atmosphere storage

In a detailed study of 15 cultivars and different gas combinations Gadalla (1997) found that all the cultivars stored in 10% CO₂ had internal spoilage after 6 months, but not after 3 months, with more spoilage when 10% CO₂ was combined with 3 or 5% O₂. All CA mixtures 1, 3 or 5% O₂ with 0 or 5% CO₂ reduced sprouting but those combinations that included 5% CO₂ were the most effective. Also the residual effects of CA storage were still effective after removal and 2 weeks at 20 °C to assess their shelf life. No external root growth was detected when bulbs were stored in 1% O₂ compared to all the bulbs in air; however, there was a general trend to increased root production with increased O₂ over the range 1–5%. Bulbs stored in 5% CO₂ had less root growth than those stored in 0% CO₂. Both these latter effects varied between cultivars. Most of the cultivars stored in 1% O₂ with 5% CO₂ and some cultivars stored in 3% O₂ with 5% CO₂ were considered marketable after 9 months storage. Gadalla (1997) also found that CA storage was most effective when applied directly after curing, but a delay of 1 month was almost as good. It was therefore concluded that with a suitable cultivar and early application of CA conditions it was technically possible to store onions at 0 °C for 9 months without chemical sprout suppressants. Waelti *et al.* (1992) converted a refrigerated highway trailer to CA storage and they found that the cultivar Walla Sweet stored well for 84 days in 2% O₂ but subsequent their shelf life was only 1 week. Yamashita *et al.* (2009) tested 1 °C and 80% r.h. in 1% O₂ + 1% CO₂ and found that sprouting and root growth were inhibited in CA storage and 98.2% were considered marketable compared to 69.2% for those stored at –0.5 °C and 80% r.h. in air after 196 days. Robinson *et al.* (1975) reported that low O₂ levels in storage reduced the respiration rate of bulbs at all temperatures studied (Table 86). Other CA storage recommendations were as follows:

- 4.4 °C with 10% CO₂ and 3% O₂ and the next best was 5% CO₂ and 5% O₂ (Chawan and Pflug 1968);
- 1 or 5 °C with 5% CO₂ and 3% CO₂ (Adamicki and Kepka 1974);
- 0–5 °C, O₂ 1–2%, CO₂ 0 and 75% r.h. (Kader 1985);
- 0–5 °C with 0–5% CO₂ and 1–2% O₂ (Kader 1989);
- 1 °C with 5% CO₂ and 3% O₂ of Granex for 7 months resulted in 99% of the bulbs considered to be still marketable with 9% weight loss and the bulbs kept well when removed from storage for marketing (Smittle 1989);
- 0–5 °C with 0–5% CO₂ and 0–1% O₂ which had only a slight effect (Saltveit 1989);
- 1 °C with 5% CO₂ and 3% O₂ (Adamicki 1989);
- 5% CO₂ with 3% O₂ were shown to reduce sprouting and root growth but controlled atmosphere storage conditions gave variable success and are not generally recommended (Hardenburg *et al.* 1990);
- 0 °C with 0% CO₂ and 1–2% O₂ (SeaLand 1991);
- 0 °C with 5 or 10% CO₂ and 1% O₂ (Mikitzel *et al.* (1993).

In contrast Stoll (1974) stated that there were indications that the early trimmed lots did not store as well in CA conditions as in conventionally refrigerated rooms and he reported better storage life at 0 °C rather than at 2 or 4 °C when the same 8% CO₂ + 1.5% O₂ atmosphere was used. Sitton *et al.* (1997) also found that storage in high CO₂ caused injury but neck rot (*Botrytis* sp.) was reduced in CO₂ levels of greater than 8.9%. They found that storage in 0.5–0.7% O₂ was firmer of better quality and had less neck rot than those stored in O₂ levels of less than 0.7%. Rotting can be affected by CA storage. In a comparison of several CA combinations Chawan and Pflug (1968) reported that the best combination in storage at 4.4 °C was 10% CO₂ + 3% O₂ and the next best was 5% CO₂ + 5% O₂. Internal spoilage of bulbs was observed in 10% CO₂ + 3% O₂ at 1.1 °C but none at 4.4 °C. Adamicki and Kepka (1974) also observed a high level of internal decay in bulbs stored in the 10% CO₂ + 5% O₂ at 1 °C, but none at 5 °C in the same atmospheric composition. The number of internally decayed bulbs increased with length of storage. Their optimum results for long-term storage were in 5% CO₂ + 3% O₂ either at 1 or 5 °C. Ogata

and Inous (1957), Chawan and Pflug (1968), Adamicki and Kepka (1974), Adamicki *et al.* (1977), Smittle (1988) and Mikitzel *et al.* (1993) all found that higher concentrations of CO₂ (usually 10%) could result in internal spoilage. Internal spoilage or internal breakdown is a physiological disorder, which appears as breakdown in the fleshy scales which may become clear when bulbs are removed to room temperature (Smittle 1988).

Hypobaric storage

McKeown and Loughheed (1981), Hardenburg *et al.* (1986) and Burg (2004) reported that onions stored at 26 °C and 58% r.h. in 60 mm Hg for 28 days lost 12.2% in weight.

Transport

For international transport they are normally transported by sea in refrigerated holds or containers. However, ventilated containers can be used. These are standard metal containers, usually 40 feet long by 8 feet wide and 8 feet high, which have no insulation or refrigeration unit but have some kind of ventilation system. They have been successfully used from Australia to transport onions to Britain.

Diseases

Lu *et al.* (1987) reported that low doses of UV-irradiation induced resistance in onions to postharvest diseases. Postharvest diseases of onions were described by Ryall and Lipton (1979) and Suslow and Cantwell (1998a) and include

- **Botrytis Neck Rot:** Symptoms include watery decay that begins at the neck and then attacks the entire bulb. A grey fungal mould then covers the neck of the bulb and later the whole bulb surface. Neck rot can be slowed after harvest, but not stopped, even during storage under optimum conditions. Proper drying in the field and during storage can decrease this postharvest fungal decay disease.
- **Black Mould Rot:** Black discolouration and shrivelling at the neck and on outer scales caused by *Aspergillus niger* van Tiegh. Infection usually occurs in the field, but the disease spreads from bulb to bulb postharvest. The surface of bulbs must be dry during and after harvest to avoid infection.

Storage at 0 °C with moderate humidity prevents the spread of this disease.

- **Blue Mould Rot:** Watery soft rot of neck and outer scales, followed by formation of blue to blue-green mould of the fungus *Penicillium* spp. Harvest of mature bulbs, proper curing and storage at 0 °C with 60–70% r.h. minimizes blue mould problems.
- **Bacterial Soft Rot:** Water-soaked individual scales or the entire onion, with foul smelling, viscous, liquid-covered, rotted areas is caused by *Erwinia carotovora* Jones. The disease progresses rapidly under warm, humid conditions. Harvesting at full maturity, proper drying, minimizing bruising and maintaining optimum storage conditions prevent bacterial soft rot.

Physiological disorders

Internal spoilage of bulbs is a physiological disorder resulting in exposure to high CO₂ concentrations. This effect was aggravated at temperatures of less than 5 °C. Chawan and Pflug (1968) observed internal spoilage of bulbs in storage at 1.1 °C in less than 10% CO₂ + 3% O₂, but there was no spoilage in the same controlled atmosphere at 4.4 °C. It was stated that 'internal spoilage of the bulbs was due to an adverse combined effect of temperature and gas concentration'. Also Adamicki and Kepka (1974) reported that Böttcher had stated that for the cultivars Ogata and Inoue there was very strong internal spoilage at concentrations of greater than 10% CO₂. They also found that after storage at 1 °C (but not at 5 °C) for more than 220 days there were 23–56% of internally spoiled bulbs when CO₂ concentrations were 10% or higher. Adamicki *et al.* (1977) found that internal breakdown was observed in 68.6% of the bulbs when they were stored at 1 °C in sealed PE bags with a CO₂ concentration higher than 10%, also they found a similar disorder in bulbs stored at 5 °C in sealed PE bags. They concluded that this was probably due to the very high concentration of CO₂ of 28.6%. Adamicki and Kepka (1974) indicated that internal spoilage of onions was due to the combined effects of high CO₂ concentrations, low temperature and a relatively long period of storage. Smittle (1989) found that the cultivar Granex stored at 5 °C in 10% CO₂ + 3% O₂ for 6 months had internal breakdown of tissue because of CO₂ toxicity.

Storage at greater than 7–8% CO₂ can lead to development of translucent scales. Late harvesting and a long drying period at high temperatures produce the highest incidence of translucent scales. Similar symptoms are caused when the bulbs have been frozen. Watery scales or leathery skin is where the bulbs develop a thick leathery skin with watery, glassy, fleshy scales below that may be affected by fungi or bacteria. The disorder is associated with late harvesting and prolonged field drying (Adamicki 2002).

Losses

Woldetsadik and Workneh (2010) reported that farm gate postharvest losses of horticultural crops in general may reach 25–35% and in shallots they estimated that it could be 30% in Sudan and 50–76% in Nigeria and Ethiopia. In a study in Yemen postharvest losses of onion were measured at about 30%. The main reason for these high losses was the seed from which the onions were grown. These were farmers' own selected seed and had been inadvertently selected to have a short storage life because they used any onion which flowered during production (Thompson 1985). Correcting this problem had to be the first consideration before any other measures are taken.

Pacific yam

Dioscoreaceae

Dioscorea nummularia Lam. synonymous with *D. spicata* Roth., *D. spicata* is synonymous with *D. nummularia* var. *glauca* Prain & Burkill, *D. spicata* var. *anammallayana* Prain & Burkill and *D. spicata* var. *parvifolia* Prain & Burkill. Other common names include hard yam and strong yam. A native of Southeast Asia and is the most important *Dioscorea* species cultivated in New Guinea and some Pacific islands. It is cultivated in many islands but in some it is collected from the bush and forest. Sturtevant (1892) reported 'TIVOLO YAM. Moluccas. This yam has cylindrical roots as thick as an arm and of excellent quality'.

Stems in the top part of the plant are round or ridged with more than four ridges while the stems at the base usually have many spines. A few poorly differentiated aerial tubers have been observed but these are very rare (Coursey 1967, Wilson and Hamilton 1988). The tubers are spindle shaped. Local

names meaning hard yam or strong yam are often given to cultivars of this species. Hard because the flesh is drier and a hard texture after cooking and strong because the growing tubers can penetrate hard, untilled soils better than other species (Wilson and Hamilton 1988).

Mohan and Kalidass (2010) gave the following analysis for *D. spicata*: moisture 89.26%, crude protein 6.38 ± 0.08 , crude lipid 4.78 ± 0.12 , crude fibre 4.67 ± 0.03 , ash 5.18 ± 0.01 , N free extractives 78.99, calorific value (kJ 100 g⁻¹ dry matter) 1605.89 g 100 g⁻¹, starch 49.36 ± 0.34 , niacin 12.31 ± 0.07 and 21.23 ± 0.12 ascorbic acid g 100 g⁻¹. They also gave *in vitro* protein digestibility as 5.27% and *in vitro* starch digestibility as 76.34%. Shajeela *et al.* (2011) reported the following analysis: starch 41.33 ± 0.33 g 100 g⁻¹, niacin 54.36 ± 0.09 g 100 g⁻¹ and ascorbic acid 76.03 ± 0.36 g 100 g⁻¹. They gave the following analysis for anti-nutritional factors: total free phenolics 1.26 ± 0.12 g 100 g⁻¹, tannins 0.26 ± 0.01 g 100 g⁻¹, hydrogen cyanide 0.10 ± 0.05 mg 100 g⁻¹, total oxalate 0.44 ± 0.07 g 100 g⁻¹, amylase inhibitor 3.31 AIU mg⁻¹ and soluble starch trypsin inhibitor 0.18 ± 0.01 TIU mg⁻¹ protein. Anti-nutritional factors identified by Mohan and Kalidass (2010) were total free phenolics 0.38 ± 0.06 g 100 g⁻¹, tannins 0.34 ± 0.06 g 100 g⁻¹, hydrogen cyanide 0.09 ± 0.03 mg 100 g⁻¹, total oxalate 0.33 ± 0.03 g 100 g⁻¹, amylase inhibitor 3.34 AIU mg⁻¹ soluble starch and trypsin inhibitor 1.39 TIU mg⁻¹ protein.

Tubers of some varieties are difficult to harvest because they are large, very long, branched and irregular in shape (Wilson and Hamilton 1988). They are formed deeply in the soil and may be allowed to grow for 2 or 3 years in order to allow the tuber to reach a size large enough to make the effort of digging worthwhile (Coursey 1967, Purseglove 1972). Other cultivars produce clusters of approximately 5–15 small tubers that are easy to harvest by digging. *D. nummularis* has a shorter dormancy period and does not store as well as *D. rotundata* (Wilson and Hamilton 1988).

Wilson (1980) described a simple method of curing *D. nummularia*. The tubers were first stacked on the ground in a lightly shaded area and covered with grass or mats. Then a canvas tarpaulin was placed over the whole stack to cover the grass or mats ensuring that the tarpaulin do not touch the yams. As an alternative,

a simple wooden frame could be built and the canvas draped like a tent over the piled yams. She indicated that plastic sheets should not be used for curing since it can make the yams too hot. If there is no canvas tarpaulin, then several layers of sacks or mats could be used.

Pak choi

Brassicaceae, Cruciferae

Brassica rapa var. *chinensis* L. It is closely related to Chinese cabbage *B. chinensis* L. var. *pekinensis* (Rupr.) Sun, and tastes similar, but has been said to have a more delicate flavour. Other common names include bok choy, pak choy, pe-tsai and celery cabbage. Pe-tsai is also called *B. rapa* (Pekinensis Group) and pak choy and bok choy are also called *B. rapa* (Chinensis Group). The edible portion is the leaves that are dark green in colour with thick, white, fleshy leaf stalks and midribs (Figure 9). The chemical content was given by USDA Nutrient Database (2012a) in Table 87. The whole plant is harvested when they have reached a marketable size, but while the leaves are still tender. They are pulled from the soil and cut-off just below the lowest leaf. At room temperature of 20 °C and 60% r.h. they could be kept for 2–3 days (Mercantilia 1989). Refrigerated storage recommendations are as follows:

- 0 °C and 95% r.h. for 10–17 days with 15% loss (Pantastico 1975);
- 0 °C and 90% r.h. for 30–40 days (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 30–40 days (SeaLand 1991).

Storage at 10 °C with 2% O₂ and 5% CO₂ increased shelf life by 112% compared to cold storage alone (O'Hare *et al.* 2000).

Parsnip

Apiaceae, Umbelliferae

Pastinaca sativa L. Wild parsnips occur in much of Europe and the Caucasus. They have been cultivated from at least Roman times and until Columbus brought potatoes to Europe, parsnips were a major

Table 87 The composition of *B. rapa* for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Pak choi Chinensis Group	Pe-tsai Pekinensis Group
Water (g)	95.32	94.39
Energy (kcal)	13	16
Protein (g)	1.50	1.20
Total lipid (fat) (g)	0.20	0.20
Carbohydrate, by difference (g)	2.18	3.23
Total dietary fibre (g)	1.0	1.2
Sugars, total (g)	1.18	1.41
Calcium (mg)	105	77
Iron (mg)	0.80	0.31
Magnesium (mg)	19	13
Phosphorus (mg)	37	29
Potassium (mg)	252	238
Sodium (mg)	65	9
Zinc (mg)	0.19	0.23
Total ascorbic acid (mg)	45.0	27.0
Thiamine (mg)	0.040	0.040
Riboflavin (mg)	0.070	0.050
Niacin (mg)	0.500	0.400
Vitamin B-6 (mg)	0.194	0.232
Folate (µg_DFE)	66	79
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	223	16
Vitamin A (IU)	4468	318
Vitamin E (α-tocopherol) (mg)	0.09	0.12
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phyloquinone) (µg)	45.5	42.9
Fatty acids, total saturated (g)	0.027	0.043
Fatty acids, total monounsaturated (g)	0.015	0.023
Fatty acids, total polyunsaturated (g)	0.096	0.072

starch staple. It is a biennial plant cultivated as an annual that thrives best in cool climates. The edible portion is the swollen taproot, which has an off white to light brown skin with concentric rings running around its' circumference. The flesh is also off white. Parsnips are among the sweetest of vegetables and were used as a sweetener before the sugar beet industry developed in the 19th century (Innvista.com 2006, Hedges and Lister 2006). They will freeze at about -2.0 to -1.5 °C (Wright 1942).

Table 88 Nutrient content of parsnips (source: adapted from USDA 2012a)

Water	79.53 g	Thiamine	0.090 mg
Energy	75 kcal	Riboflavin	0.050 mg
Protein	1.20 g	Niacin	0.700 mg
Total lipid (fat)	0.30 g	Vitamin B-6	0.090 mg
Carbohydrate, by difference	17.99 g	Folate, DFE	67 µg_DFE
Total dietary fibre	4.9 g	Vitamin B-12	0.00 µg
Sugars, total	4.80 g	Vitamin A, RAE	0 µg_RAE
Calcium	36 mg	Vitamin A, IU	0 IU
Iron	0.59 mg	Vitamin E (α-tocopherol)	1.49 mg
Magnesium	29 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus, P	71 mg	Vitamin D	0 IU
Potassium, K	375 mg	Vitamin K (phyloquinone)	22.5 µg
Sodium, Na	10 mg	Fatty acids, total saturated	0.050 g
Zinc, Zn	0.59 mg	Fatty acids, total monounsaturated	0.112 g
Vitamin C, total ascorbic acid	17.0 mg	Fatty acids, total polyunsaturated	0.047 g

Hedges and Lister (2006) reported that their water content was 81.9 g 100 g⁻¹ fresh weight and the levels of carbohydrate were 1.5 g glucose, 1.5 g fructose, 5.9 g sucrose and 2.35 g 100 g⁻¹ starch on a fresh weight basis. Detailed analysis was given by USDA (2012a) (Table 88). Rutherford (1977) found that monosaccharide's decreased during 6–7 months of storage while insoluble sugars increased mainly over the first 2½ months. Parsnips are low in antioxidant pigments but contain falcarinol and are a good source of fibre and potassium and also contain calcium, iron, magnesium and 69.5 µg total folate 100 g⁻¹ fresh weight (Hedges and Lister 2006).

Harvesting

It is a long season crop and they are harvested when they achieve a size acceptable for the market, which may take over 3 months. In northern Europe this is in autumn, but they may be harvested when immature and marketed as 'baby parsnips'. Lutz and Hardenburg (1968) and Phillips and Armstrong (1967) reported that they were not injured by slight freezing. In contrast quality and sweetness were shown to be improved by delaying harvesting so that they were exposed to frost for 2 months (Lutz and Hardenburg 1968). Cold temperatures encourage the conversion

of starch to sugar. They can be harvested mechanically using modified carrot harvesters.

Pre-cooling

Hydrocooling was the most suitable method of pre-cooling, forced air cooling with high humidity was also suitable, air cooling in a conventional cold store was less suitable and vacuum cooling was unsuitable (MAFF n.d.). Holmes and Kemble (2009) recommended room cooling for parsnips grown in the southern United States. Rapid cooling to 5 °C or below immediately after harvest was reported to be essential to minimize decay and moisture losses during extended storage (Toivonen 2002).

Postharvest physiology

They produce very low amounts of ethylene at less than 0.1 µl kg⁻¹ h⁻¹ at 20 °C (Toivonen 2002). Exposure to ethylene was shown to increase their respiration rate especially if ethylene accumulates in stores when they were stored with climacteric fruit (Rhodes and Woollorton 1971). Also exposure to low levels of ethylene in cold storage causes bitterness, probably due to accumulation of xanthotoxin (8-methoxypsoralen) (Johnson *et al.* 1973, Shattuck *et al.* 1988). Respiration rate is given in Table 89.

Storage

The main limiting factor in storage is root discoloration and shrivelling (Phillips and Armstrong 1967). At room temperature of 20 °C and 60% r.h. they could be kept for 4–6 days (Mercantilia 1989). Storing the parsnips at near freezing temperatures encourages the conversion of starch to sugar and an improvement in quality can be achieved by storage for 2–3 weeks at 0–1.1 °C (Wardlaw 1937, Lutz and

Hardenburg 1968). Refrigerated storage recommendations include

- 0 °C and 90–95% r.h. for 2–4 months (Wardlaw 1937);
- 0 °C and 95% r.h. for 2–4 months (Phillips and Armstrong 1967);
- 0 °C and 90–95% r.h. for 2–6 months (Anonymous 1967, Lutz and Hardenburg 1968);
- 0–1 °C and 98% r.h. for 4–6 months (van den Berg and Lentz 1973);
- 0 °C and 90 r.h. for 2–6 months (Mercantilia 1989);
- 0 °C and 98–100% r.h. for 4–6 months (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 120–150 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 2–6 months (Snowdon 1991);
- 0 °C and 98–100% r.h. for 4–6 months for parsnips grown in the southern United States (Holmes and Kemble 2009).

Modified atmosphere packaging

Perforated polyethylene film liners in storage boxes reduces shrivelling (Lutz and Hardenburg 1968) as did packing in sphagnum moss (Phillips and Armstrong 1967), sand or clean soil (Lutz and Hardenburg 1968).

Diseases

Parsnip canker or itersonilia canker (*Itersonilia perplexans* Derx. or *I. pastinacae* Channon) is the most important disease of parsnips but does not appear to infect carrots. Some work has been done to select resistant cultivars (Snowdon 1991). Other diseases include grey mould rot (*Botrytis cinerea* Pers.:Fr.), bacterial soft rot (*Erwinia carotovora* (Jones) Bergey *et al.*) and watery soft rot (*Sclerotinia sclerotiorum* (Lib.) de Bary) (Smith *et al.* 1982).

Physiological disorder

Surface browning is a significant physiological disorder that is largely associated with bruising and abrasion injury during harvest. Crops grown on coarse sandy soils are more susceptible and surface browning can increase during storage. There are cultivars that are resistant to browning and postharvest dips

Table 89 Respiration rates of parsnips at different temperatures (source: adapted from Smith 1957; van den Berg and Lentz 1972)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	8–16
5	8–18
10	19–25
15	30–43

reduced browning during storage, but waxing can increase browning (Toivonen 2002).

Papa criolla

Solanaceae

Solanum phureja Juz. & Buk. It was classified as *S. phureja* by Hawkes (1990), as *S. tuberosum* Phureja group by Huamán and Spooner (2002) and Rivera *et al.* (2011) and as *S. tuberosum* Andigenum group by Spooner (2010). Other common names include criolla, criolla Colombia and creole potato. They originated in the Andean region of South America. Colombia was the main producer with about 150,000 tonnes per year on approximately 25,000 ha of land (Porrás 2000). However the Ministry of Agriculture and Rural Development in Bogotá in 2011 estimated that there were about 8000 ha of papa criolla in the departments of Cundinamarca, Boyacá and Nariño. They are grown between 2000 and 3000 m with the optimal growing conditions between 2300 and 2800 m. The most common cultivar is Yema de Huevo (Porrás 2000) referring to its bright yellow colour.

The edible portion is the stem tuber, which has deep eyes, a yellow skin and flesh that can vary from white to yellow. They resemble a small potato (*S. tuberosum*) and have a nice nutty texture (Figure 45). Bonierbale *et al.* (2004) and Cisneros-Cevallos (2008) reported that the tubers contain carbohydrates, proteins of high biological value, vitamin C and vitamin B complex, Fe, Zn, Cu, Ca, phenolic compounds, carotenoids and alkaloids. The



Figure 45 Papa criolla being distributed in plastic bags in wooden boxes to retail stores in Bogotá in Colombia in 1976.



Figure 46 Papa criolla in woven polypropylene sacks on the wholesale market in Bogotá in Colombia. See colour plate section.

best tuber characteristics for individually quick frozen (IQF) and pickling were yellow coloured peel, round shape, shallow 'eyes', 16–20.5% dry matter, 2.5–3.5 cm in diameter and less than 0.1% reducing sugars. For dehydrated flakes the tubers with 21–25% dry weight, large size and reducing sugars below 0.1% were preferred (Rivera *et al.* 2011).

The main limitation to storage is sprouting. This could occur within a week of harvesting at room temperatures in Bogotá (24–26 °C and 40% r.h.). Tubers also lost 25% in weight within a week at these temperatures and rapidly became discoloured and infected with fungi (Amezquita García 1973). He also gave the optimum refrigerated storage temperature as 10–15 °C and 85–90% r.h. They are frequently stored for short periods in woven polypropylene sacks in ambient conditions in warehouses in the Central Market in Bogotá (Figure 46).

Pea

Fabaceae, Leguminosae

Pisum sativum L. Other common names include garden pea, mange tout, snow pea and sugar pea. Three varieties of *P. sativum* have been recognized:

- *P. sativum* var. *humile* or *P. sativum* var. *sativum* L. are grown for their seeds and have a tough pod, which is discarded prior to eating.
- *P. sativum* var. *macrocarpon* Ser. are grown for their pods. Snow peas are also referred to as *P. sativum* var. *saccharatum*. The Mange tout, Snow

pea or Sugar pea have flat pods with minimal development of the seeds, while the Sugar Snap pea or Snap pea has well-developed seeds and is fully rounded. The Sugar Snap pea is the result of a cross between the snow pea and an unusual tightly podded pea with thick walls.

- *P. sativum* var. *arvense* are grown for animal feed, dried peas and green manuring.

It probably originated in southwest Asia and has been cultivated in southern Europe since Roman times. They are now grown in temperate areas around the world. It is a glaucous climbing annual usually with white flowers and tendrils that are actually modified leaves. In most cases the edible portion is the pod or the seeds that are produced within the pod or legume. All varieties of peas grow best under cool, moist conditions. Green peas will freeze at about -1.3 to -1.0 °C (Wright 1942) or -1.17 to -0.61 °C (Weichmann 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 90.

Harvesting

As the peas develop they accumulate sugars and as they mature sugar is converted into starch and they become firmer and less tender. Harvest maturity for the seeds is when the pods are well filled, but they are still young, tender and sweet. Small-scale growers usually harvest the peas by hand as they mature every 5–10 days. For mange tout, snow peas and sugar peas harvesting is before the seeds have swollen in the pods.

For processing sample peas are tested in a shear cell called a tenderometer to assess their texture (Knight 1991). The whole field of peas is harvested when a particular tenderometer value is reached. However, in many cases the farmer will simply sample the peas and squeeze them between his fingers to determine their firmness and taste them to test their sweetness. On the basis of experience the farmer will be able to tell whether or not to harvest that field of peas. Tenderometers are destructive tests that assume the sample taken is representative of the crop, but special processing cultivars have been bred where all the pea pods mature at about the same time. In recent years the process has been developed where a sample of peas are taken at intervals across a field to ensure that is representative. These are placed in

Table 90 The composition of peas for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Snowpeas, sugar snap peas	Green peas
Water (g)	88.89	78.86
Energy (kcal)	42	81
Protein (g)	2.80	5.42
Total lipid (fat) (g)	0.20	0.40
Carbohydrate, by difference (g)	7.55	14.45
Total dietary fibre (g)	2.6	5.1
Sugars, total (g)	4.00	5.67
Calcium (mg)	43	25
Iron (mg)	2.08	1.47
Magnesium (mg)	24	33
Phosphorus (mg)	53	108
Potassium (mg)	200	244
Sodium (mg)	4	5
Zinc (mg)	0.27	1.24
Total ascorbic acid (mg)	60.0	40.0
Thiamine (mg)	0.150	0.266
Riboflavin (mg)	0.080	0.132
Niacin (mg)	0.600	2.090
Vitamin B-6 (mg)	0.160	0.169
Folate (µg_DFE)	42	65
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	54	38
Vitamin A (IU)	1087	765
Vitamin E (α-tocopherol) (mg)	0.39	0.13
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phyloquinone) (µg)	25.0	24.8
Fatty acids, total saturated (g)	0.039	0.071
Fatty acids, total monounsaturated (g)	0.021	0.035
Fatty acids, total polyunsaturated (g)	0.089	0.187

the tenderometer which measures the resistance to crushing and records the reading directly onto a lap-top computer. The computer, in turn, sends a text to the persons operating the harvesting machines who can then arrange the harvesting schedule by comparing the readings with those from other fields. It is standard practice in the United Kingdom to ensure that the time between harvesting and freezing does not exceed 2½ h to achieve the AA grade. Where longer times occur the product will be regraded to B or even C grade. Where the peas cannot be harvested

in time then they are often allowed to fully mature and harvested with a pea viner when they have dried. These may be used as seed if there is a demand and royalty obligations to the seed company are met or they may be used as animal feed.

Some work was done on heat units in relation to harvest maturity. The number of degree hours above 4 °C is calculated. This varies between cultivars and is usually within 30,000 and 35,000, but it has limited application. However, day degrees and heat units are used to compute harvest dates for vining peas (John Love, personal communication, quoted by Thompson 1996).

For processing they are harvested in combine machines called pea viners. These machines harvest the whole plant, remove the pods from the vines and shell the pods thus removing the peas. Physical damage during harvesting has been shown to adversely affect the flavour of peas (Murray *et al.* 1976), but since they are frozen within an hour or so of harvesting this is not normally a problem in a well run processing industry.

Pre-cooling

Ryall and Lipton (1979) recommended forced air cooling, hydrocooling or vacuum cooling. They found that if vacuum-cooling was used it was important that the peas were pre-wetted to ensure rapid cooling. Forced air cooling with high humidity was the most acceptable; hydrocooling was suitable and air cooling in a conventional cold store and vacuum cooling less suitable (MAFF n.d.). After 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of –1.7 to 0 °C Barger (1963) found that the pea temperature fell from 20 to 22.2 to 6 °C. Pre-cooling with crushed ice may extend their storage life from about a week to 15–20 days (Tindall 1983).

Postharvest physiology

Peas produce very low levels of ethylene at less than 0.1 µl kg⁻¹ h⁻¹ at 20 °C, but they are moderately sensitive to ethylene after harvest, which results in yellowing and increased decay (Suslow and Cantwell 1998a). However, they showed no response in respiration rate to exposure to 100 µl L⁻¹ of ethylene for 24 h at any temperature over the range 5–35 °C (Inaba *et al.* 1989). Respiration rates are given in Table 91.

Table 91 Respiration rates of peas in milligrams carbon dioxide per kilogram per hour at different temperatures (source: adapted from Suslow and Cantwell 1998a)

Temperature (°C)	Garden peas	Edible-pod peas (estimate)
0	30–46	30–48
5	55–72	53–74
10	63–108	65–112
15	165–185	165–187
20	220–322	221–324
25	298–327	–

Storage

For the fresh market garden peas store better in the pods than when shelled. At room temperature of 20 °C and 60% r.h. peas could be kept for about 1 day and mange tout for 1–2 days (Mercantilia 1989). Refrigerated storage recommendations are as follows:

- 0 °C and 80–90% r.h. for 25 days with 5% loss or 32 days with 10% loss (Wardlaw 1937);
- 0.6 °C and 85% r.h. for 4 weeks (Wardlaw 1937);
- –0.5 to 0 °C and 85–90% r.h. for 1–3 weeks (Anonymous 1967);
- 0 °C and 90–95% r.h. for 1–2 weeks (Lutz and Hardenburg 1968);
- 0 °C and 85–90% r.h. for 1–2 weeks (Lutz and Hardenburg 1968);
- 0 °C and 88–92% r.h. for 2–3 weeks with 8% loss (Pantastico 1975);
- 0 °C and 95–100% r.h. for up to 10 days with a weight loss of up to 10% (Tindall 1983);
- 4 °C and 95–100% r.h. for 6–7 days (Tindall 1983);
- 0 °C and 90–95% r.h. for 7 days (Mercantilia 1989);
- 4 °C for 4 days (Mercantilia 1989);
- 12 °C for 2 days (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 1–2 weeks for mange tout (Mercantilia 1989);
- 0 °C and 95–98% r.h. for 1–2 weeks (Hardenburg *et al.* 1990);
- 0 °C and 90–95% r.h. for 7–10 days for both peas and snow peas (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 1–3 weeks (Snowdon 1991);
- 0–1 °C and 95–100% r.h. for 1–2 weeks for mange tout (Snowdon 1991);
- 0 °C and 95–98% r.h. for 1–2 weeks (Suslow and Cantwell 1998a).

Controlled atmosphere storage

Pantastico (1975) reported that in storage at 0 °C peas in their pods could be kept in good condition for 7–10 days while in 5–7% CO₂ + 5–10% O₂ they could be kept for 20 days. At 0 °C their quality was better after 20 days in 5–7% CO₂ than in air (Tomkins 1957). Storage at 0 °C in 5–7% CO₂ maintained their eating quality for 20 days (Hardenburg *et al.* 1990). Fellows (1988) recommended a maximum of 7% CO₂ and a minimum of 5% O₂. However, Suslow and Cantwell (1998a) reported that there was no benefit in controlled atmosphere storage compared to storage in air at the same temperature, although they reported that snow peas and snap peas responded moderately to storage in 2–3% O₂ + 2–3% CO₂. Monzini and Gorini (1974) recommended 0 °C in 5% CO₂ + 21% O₂ for 20 days. Saltveit (1989) recommended 0–10 °C in 2–3% CO₂ + 2–3% O₂ for sugar peas which had only a slight effect. Pariasca *et al.* (2001) showed that storage at 5 °C in 5–10% O₂ + 5% CO₂ were the best conditions among those that they tested, since changes in organic acid, free amino acid, sugar content and pod sensory attributes were slight. The appearance of pods stored in controlled atmosphere storage was much better than that those stored in air. They also found that 2.5% O₂ + 5% CO₂ and 5% O₂ + 10% CO₂ had a detrimental effect on quality since they developed slight off-flavours, but this effect was partially alleviated after ventilation.

Modified atmosphere packaging

Pariasca *et al.* (2001) stored snow pea pods at 5 °C in PPP films of 25 and 35 µ thicknesses. They found that internal quality was maintained and that appearance, colour, chlorophyll, ascorbic acid, sugar content and sensory scores were retained better than those stored without packaging. The equilibrium atmosphere in both thicknesses of bags was around 5% O₂ + 5% CO₂.

Diseases

Snowdon (1991) reported the following diseases that can affect peas postharvest: alternaria blight *Alternaria alternata*, anthracnose *Colletotrichum*, ascochyta pod spot caused by *Ascochyta pisi* Lib. and Powdery Mildew *Erysiphe* spp. Common diseases for edible podded peas were grey mould *Botrytis cinerea*

that can be a problem at the blossom end of freshly cut pods, watery soft rot *Sclerotinia sclerotiorum*, Rhizopus rot *Rhizopus* sp. and bacterial soft rot.

Pecan

Juglandaceae

Carya illinoensis (Wangenh.) K. Koch. It originated in the southern United States and Mexico where it has been used by the indigenous population for centuries. It is a deciduous tree usually growing to 40 m in height, with a typical spread of 12–23 m. The flowers are wind-pollinated and monoecious. The male catkins are pendulous, up to 18 cm long; the female catkins are small, with three to six flowers clustered together. Nuts comprise the kernel (cotyledons) that is divided into two relatively equal sized halves that is surrounded by a hard shell. They are classified either as seedling or cultivars since seedling typically has thicker shells with smaller kernels. The majority of commercial production is the cultivars including Western, Desirable, Stuart, Wichita and Pawnee (Maness 2004). Herrera (2005) reported that good quality kernels contain 12–15% carbohydrates, 9–10% proteins, 3–4% water, about 1.5% minerals and 73–75% oil, of which 93% is unsaturated and they are cholesterol free. The chemical content was given by USDA Nutrient Database (2012a) in Table 92.

Harvesting and handling

Immature kernels have a moisture content of 25–30%, which decreases as they mature and should be stored at a moisture content of about 4%. Moisture content needs to be decreased as soon as practical after harvesting to prevent fungal contamination, discolouration and breakdown of the oil (Herrera 2005). The edible seed is surrounded by a shuck that dehisces when the seed is mature. Nuts are harvested in late autumn and early winter by mechanical shaking the trees and gathering the nuts from the ground (Maness 2004). Gardea *et al.* (2011) described windrowing which is accomplished to facilitate harvesting by using a tractor fitted with a 'V-rake' attached to the front. They also mentioned that a canvas sheet may be spread below the trees to facilitate collection. The nuts are placed in containers

Table 92 The composition of pecan nuts for 100 g⁻¹ fresh weight (USDA 2012a)

Energy	690 kcal	Riboflavin (vitamin B-2)	0.13 mg
Carbohydrates	13.86	Niacin (vitamin B-3)	1.167 mg
Starch	0.46	Pantothenic acid (vitamin B5)	0.863 mg
Sugars	3.97	Vitamin B-6	0.21 mg
Dietary fiber	9.6	Folate (vitamin B9)	22 µg
Fat	71.97	Vitamin C	1.1 mg
Saturated	6.18	Vitamin E	1.4 mg
Monounsaturated	40.801	Vitamin K	3.5 µg
Polyunsaturated	21.614	Calcium	70 mg
Protein	9.17	Iron	2.53 mg
Water	3.52	Magnesium	121 mg
Vitamin A	56 IU	Manganese	4.5 mg
β-carotene	29 µg	Phosphorus	277 mg
Lutein and zeaxanthin	17 µg	Potassium	410 mg
Thiamine (vitamin B1)	0.66 mg	Sodium	0 mg
		Zinc	4.53 mg

for transport to a packhouse for cleaning and grading ready for packaging.

Postharvest physiology

They have a low respiration rate at <5 mg (2.5 ml) CO₂ kg⁻¹ h⁻¹ at 5 °C and produce very low amounts of ethylene but prolonged exposure to ethylene may cause pecans to darken and shorten their shelf life (Maness 2004).

Storage

Mechanically harvested in-shell pecans should be dried to 4.5% moisture prior to storage to preserve quality and prevent mould growth (Heaton *et al.* 1977). Shelled nuts contain 7–9% moisture after shelling and should be dried to 3–4% moisture to maintain quality. Drying temperatures greater than 38 °C should be avoided because they cause them to darken. Recommended conditions for storage were <2 °C with 70% r.h. In-shell pecans can be stored at 22 °C for 6 months, 0 °C for 12 months or –18 °C for 2 years, whereas shelled pecans can only be stored for 3 months at 22 °C, 9 months at 0 °C or 18 months at –18 °C (Woodroof and Heaton 1962). Storage of kernel pieces should be limited to

1 or 2 months at temperatures about 0 °C. Shelled kernels stored at non-freezing temperatures should be maintained in about 65–70% r.h. to retain 3–4% moisture content since higher humidity can cause fungal contamination and they may become soft and rubber-like and darken under as a result of the tannic acid being translocated from the shell lining (Herrera 2005). Pecans still in their shells could remain in good for 4 months at 21 °C, 18 months at 0–2 °C and up to 5 years or more when stored at –18 °C

Pepino

Cucurbitaceae

Cyclanthera pedata (L.) Schrad. var. *edulis* (Naudin) Cogn. Other common names include caigua, cyclanthera and wild cucumber. It is not known in the wild but has been claimed to be native to Mexico. It has been domesticated in the Andes from Colombia to Bolivia and is now grown in many parts of Central America, India, Nepal and Bhutan. The fruit is an edible, fleshy berry-like structure called a pepo that is yellowish or green slightly spiny, ovoid in shape, about 5 cm long and hollow with many seeds. It has a strong smell. The young shoots and leaves may also be eaten as greens. The only recommendation that could be found is 7–10 °C and 85–90% r.h. for 1–2 weeks (Hardenburg *et al.* 1990).

Plantains

Musaceae

They belong to the section *Eumusa* of the genus *Musa*. The Linnaean classification of 1783 gave the name for *Musa* that are cooked, for example plantains and cooking bananas, as *M. paradisiaca* L. Cheesman (1947–1949) defined the two species, *M. balbisiana* Colla and *M. acuminata* Colla as the basis for almost all cultivated bananas and plantains. *M. balbisiana* has also contributed to the origin of desert bananas and plantains by hybridization with *M. acuminata*. Simmonds and Shepherd (1955) recommended that in place of the species name, an A genome or a B genome should be used showing the origin and contribution of the two species. Plantains are *Musa* AAB and are classified into two subgroups as either French plantains types, which contain at least nine forms, or Horn plantains types with

Table 93 World production of plantains in million tonnes (source: adapted from FAO 2013)

Year	1961	1971	1981	1991	2001	2011
Production	12.7	20.0	22.4	27.3	31.5	38.9

an undetermined number of forms. It seems likely that both the French and Horn types have a common origin (Stover and Simmonds 1987). Recently released *Musa* AAAB plantain or cooking banana cultivars by the Fundacion Hondureña de Investigacion Agricola are FHIA-03, FHIA-20, FHIA-25 and FHIA-21. FHIA-21 is a cooking banana with plantain in its pedigree and is reported to be resistant to Black Sigatoka disease and has total fingers per bunch and bunch weights at maturity about double those of False Horn (*Musa* AAB). With the exception of these FHIA cultivars the source of probably all the varieties of plantain cultivated had originated from somatic mutations that had been recognized in the field by growers. It is an increasingly important crop with production having increased by over threefold in the last 50 years (Table 93).

The plant has a basal corm, the true stem, which has an apical meristem in the form of a flattened crown from which grow the spirally arranged leaves whose bases form a pseudostem. The flower is produced from the corm in the centre of the leaves and emerges at the top of the pseudostem. Only one flower is produced from one pseudostem. It takes about a month from formation to emergence of the inflorescence. The inflorescence is borne on a stout peduncle and consists of male and female flowers borne on nodes in two rows of nodal clusters with bracts in between. The top 5–15 nodal clusters produce female flowers and below this at the distal end, male flowers. There may be hermaphrodite flowers between the male and the female. The root system is adventitious with individual roots up to about 8 mm in diameter with primary roots producing short thinner lateral roots. They are white and fleshy later becoming somewhat corky and can spread up to 5 m laterally but mostly in the top 15 cm and to a depth restricted by the water table. The fruit is a climacteric parthenocarpic berry. They are similar to bananas but have higher starch content. Hulme (1971) gave this as about 30% for green fruit reducing to 5–10% when they are fully ripe. At 20 °C Marriott *et al.* (1983) showed

Table 94 The composition of plantain fruit (*Musa × paradisiaca*) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	65.28 g	Thiamine	0.052 mg
Energy	122 kcal	Riboflavin	0.054 mg
Protein	1.30 g	Niacin	0.686 mg
Total lipid (fat)	0.37 g	Vitamin B-6	0.299 mg
Carbohydrate, by difference	31.89 g	Folate	22 µg_DFE
Total dietary fibre	2.3 g	Vitamin B-12	0.00 µg
Sugars, total	15.00 g	Vitamin A	56 µg_RAE
Calcium	3 mg	Vitamin A	1127 IU
Iron	0.60 mg	Vitamin E (α-tocopherol)	0.14 mg
Magnesium	37 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	34 mg	Vitamin D	0 IU
Potassium	499 mg	Vitamin K (phyloquinone)	0.7 µg
Sodium	4 mg	Fatty acids, total saturated	0.143 g
Zinc	0.14 mg	Fatty acids, total monounsaturated	0.032 g
Total ascorbic acid	18.4 mg	Fatty acids, total polyunsaturated	0.069 g

that starch degradation was slower than in Cavendish bananas and was not complete in over-ripe fruits. Total sugar content continued to increase after full maturity and was still increasing in over-ripe fruits. Sucrose comprised about 70% of total sugars when plantains became fully yellow but this proportion fell to about 50% when the fruits became over-ripe. Ripe plantains, fully yellow but showing no blackening, contained 3–12% starch and 18–28% total sugars on a fresh weight basis. Like most other fruits they are acid with a pulp pH below 4.5. They can contain high levels of phenolic compounds especially in the peel (Von Loesecke 1950). The chemical content was given by USDA Nutrient Database (2012a) in Table 94.

Harvesting

Maturity is usually assessed by the shape or 'angularity' of the fingers where the fruit in cross section becomes progressively more rounded and less angular as it matures. The most common maturity is full or full $\frac{3}{4}$, where full is almost completely rounded in cross section, see under bananas for an explanation. Increasing fruit maturity at harvest significantly increased ripening rate of harvested fruits (Ferris *et al.* 1993b). Optimum harvest time can vary with

variety and the best harvesting stages in weeks before ripeness of the first finger on the bunch were given by Tchango *et al.* (1999) as follows:

- 1 week for French Clair with a flowering to harvesting interval of 79 days;
- 1–2 weeks for Big Ebanga with a flowering to harvesting interval of 71–78 days;
- 2–3 weeks for Batard with a flowering to harvesting interval of 68–75 days.

Handling and packaging

Damage can reduce the green life of fruits. The effects of different types of bruise on the ripening of plantains showed that the greatest effect was caused by abrasion. Ripening rate of French, True Horn and False Horn during storage in ambient conditions averaging 28 °C and 82% r.h. was increased when fruit had been damaged by abrasion, more so in less mature fruits, and also by impact, but only in immature fruits (Ferris *et al.* 1993b). For some local markets damage and blackening of the peel does not adversely affect their marketability. A study carried out in Ghana showed that even fruit that had been crushed to a pulp were readily saleable and often had specialized markets (Ferris 1991, Ferris *et al.* 1995).

In experiments it was shown that plantains stored in cartons without a packing material lost weight rapidly during ripening and became blackened and shrivelled. Those packed in dry coir dust lost less weight and those in moist coir dust gained weight; no shrivelling was seen following the latter two treatments and there was less skin blackening. The fruits in coir dust remained green for long periods before ripening rapidly. However, they took up moisture and would eventually split if stored for too long.

Coating

Coating fruits in Semperfresh, a commercially available material based on sucrose esters of fatty acids and sodium carboxy methyl cellulose, which had been shown to reduce the gaseous exchange between fruits and the outside air, did not impede initiation of ripening by exposure to ethylene. The major changes associated with ripening were generally slower for coated fruits than for fruits ripened without coating. There was some indication, especially where a thick layer of Semperfresh was applied, that the

rate of degreening was slowed more than that of other ripening processes. The effects on fruit weight loss were generally related to the storage humidity, with the coating having a large inhibitory effect on weight loss in fruits ripened at lower humidity and little or no effect on weight loss in fruits ripened at higher humidity. Taste panels were unable to detect organoleptic differences between fruits ripened with and without coating (Al-Zaemey *et al.* 1989). Chukwu *et al.* (1995) found that the combination of vacuum infiltration with 1% calcium chloride for 10 min followed by immersion in a 1.5% solution of Semperfresh extended the green life of Agbagba and the hybrid TMP X 2796-5 without adverse effects. Demerutis Pena *et al.* (2000) treated fruits of 11, 12 and 13 weeks of age with experimental waxes (from FMC Company) and commercial ethylene scrubbers. Laboratory and shipping trials from Venezuela to Europe indicated that SF 965 wax at 25% gave good results, but only when pathogens on the fruits were fully controlled. As this is difficult to attain, the use of ethylene scrubbers with bagged fruits is recommended.

Storage

Refrigerated storage recommendations are as follows:

- 10 °C and 85–90% r.h. for green fruit for 5 weeks with 6% loss (Pantastico 1975);
- 7.2–10 °C and 85–90% r.h. for ripe fruit for 10 days (Pantastico 1975);
- 10 °C and 85–90% r.h. for 5 weeks (Snowdon 1991);
- 11–15.5 °C and 85–90% r.h. for coloured fruit for 1–3 weeks (Snowdon 1990);
- 14.4 °C and 85–95% r.h. for 10–35 days (SeaLand 1991);
- 12–14 °C and 85–95% r.h. for 15 days for green mature fruits (Tchango *et al.* 1999).

Humidity

Exposing fruit to sufficient stress can initiate ripening. Low humidity in the storage atmosphere will result in stress and can initiate ripening and thus resulted in a reduced storage life (Thompson *et al.* 1972a, 1972b, 1974b). Maintaining high humidity around the fruit can help to keep fruit in the pre-climacteric stage so that where fruit were stored in

moist coir dust or individual fingers were sealed in polyethylene film they can remain green and preclimacteric for over 20 days in Jamaican ambient conditions (Thompson *et al.* 1972a, 1972b, 1974a). Such fruit ripened quickly and normally when removed. Fruits stored at 20 °C and 96–100% r.h. ripened about 15 days later than those stored at 20 °C and 55–65% r.h. (Ferris *et al.* 1993a). Fruits kept in desiccators with air passing over them at 0% r.h. became visibly ripier than those with air at 100% r.h. passing over them (Thompson *et al.* 1974a).

Controlled atmosphere storage

SeaLand (1991) recommended was 14.4 °C and 85–95% r.h. with 2–5% CO₂ and 2–5% O₂. Agoreyo *et al.* (2007) found that ethylene production was not detected in fruit in controlled atmosphere storage also they had an increased postharvest life when compared to fruit stored in air.

Modified atmosphere packaging

Plantains stored in modified atmospheres had a considerably longer postharvest life than those stored unwrapped (Table 95). The degree of perforation in the bag has a large effect on the atmosphere inside the bag. In another experiment plantains packed with six fruits in a bag ripened in 14.6 days at 26–34 °C compared to 18.5 days when fruits were packed individually (Figure 47) (Thompson *et al.* 1972a, 1972b). The effects of PE film wraps on the postharvest life of plantains may be related to moisture conservation around the fruit as well as the change in the CO₂ and O₂ content. This was shown by Thompson *et al.* (1972a, 1972b) where fruit stored in moist coir or perforated 25 µm PE film bags had a longer storage life

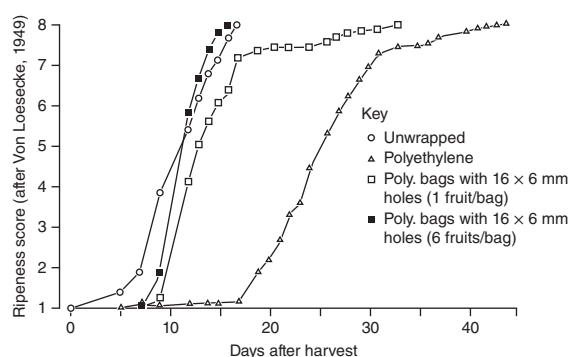


Figure 47 Effects of wrapping material on the rate of ripening of plantains in Jamaican ambient conditions.

than fruits which had been stored non-wrapped. But there was an added effect when fruits were stored in non-perforated PE bags which were presumably due to the effects of the changes in the CO₂ and O₂ levels. So the positive effects of storage of preclimacteric plantains in sealed plastic films may be, in certain cases, a combination of its effects on the CO₂ and O₂ content within the fruit and the maintenance of high moisture content. Maintaining high humidity around the fruit can help to keep fruit in the preclimacteric stage so that where fruit were stored in moist coir dust or individual fingers were sealed in PE film they can remain green and preclimacteric for over 20 days in Jamaican ambient conditions of about 28 °C. Such fruit ripened quickly and normally when removed from the plastic film. Since packing in moist coir proved as effective as modified atmosphere packaging it could be that the effects of modified atmosphere packaging on plantains is due entirely or at least partially to humidity rather than changes in O₂ and CO₂ inside the bags (Thompson *et al.* 1972a, 1972b).

Table 95 Effects of wrapping and packing material on ripening and weight loss of plantains stored at tropical ambient conditions of 26–34 °C and 52–87% r.h. (source: adapted from Thompson *et al.* 1972b)

Packing material	Days to ripeness	Weight loss at ripeness
Not wrapped	15.8	17.0%
Paper	18.9	17.9%
Moist coir fibre	27.2	3.5% ^a
Perforated PE	26.5	7.2%
PE	36.1	2.6%
LSD ($p = 0.05$)	7.28	2.81

^aThe fruit actually gained 3.5% in weight.

Ripening

The pulp:peel weight ratio increased from 1.23 in green plantains to 1.60 when fully ripe. Starch content for green and ripe fruits were 27.10 and 8.21%, respectively, total sugars contents were 1.13 and 19.91%, respectively, soluble solids 3.67 and 22.47%, respectively, pH 5.41 and 4.35, respectively and moisture content 70.63 and 71.87%, respectively (Fernandez *et al.* 1996). The pigments in the peel of plantains are chlorophylls and carotenoids. The change in colour of ripening fruits is associated with

the breakdown of chlorophylls with carotenoid levels remaining relatively constant (Seymour 1985). With plantains it was shown that complete chlorophyll destruction could occur even at 35 °C (Seymour 1985, Seymour *et al.* 1987b). As they ripen the ratio of the mass of the pulp to the mass of the peel increases and the peel becomes progressively easier to detach from the pulp. The onset of the starch to sugar conversion has been shown to be influenced by harvest maturity, with more mature fruits responding earlier. In bananas the breakdown of starch is usually completed during ripening, but in plantains this breakdown is not completed even when the fruit is fully yellow and soft (George 1981). Tannins are perhaps the most important phenolic from the point of view of fruit utilization because they can give fruit an astringent taste. As fruit ripens their astringency becomes lower which seems to be associated with a change in structure of the tannins, rather than a reduction in their levels, in that they form polymers (Von Loesecke 1950, Palmer 1971).

At 30 °C and 88% r.h. fruits of the cultivar Rose d'Ekona reached colour stage 7 (fully yellow with black spots) after only 6 days, compared with 10–12 days for French Clair, Big Ebanga, two Hands Planty (Horn plantain) and Batard. At stage 7, the weight loss of French Clair was 22.8%, compared to 12.6–16.8% for the other cultivars (Ngalani *et al.* 1998). 22–24 °C was used by Fernandez *et al.* (1996) in Cuba. Optimum ripening condition was given as 22.2 °C and 85–100% r.h. with 1000 µl L⁻¹ ethylene by Sanchez Nieva *et al.* (1970). In these conditions the fruit were fully yellow with soft pulp in 4–5 days.

Diseases

The postharvest diseases are the same as those that affect bananas. They are highly resistant to Panama disease, generally resistant to yellow Sigatoka and susceptible to black Sigatoka (Stover and Simmonds 1987).

Pistachio

Anacardiaceae

Pistacia vera L. It is a native of western Asia and Asia Minor where it can still be found growing wild in hot, dry locations. The tree can grow to 12 m

high but are usually smaller and for commercial production they are usually grafted onto a rootstock e.g. *P. terebinthus* L. Trees are dioecious; therefore orchards must include the appropriate ratio of female to male trees. Since trees are propagated vegetatively this is easily achieved by planting a female cultivar e.g. Kerman, Ashouri, Red Oleimy and White Batoury and a male cultivar e.g. Peters at the appropriate ratio and siting. The nut is an oval drupe about 1–2 cm long with an edible brilliant green coloured kernel contained in an edible testa. The testa contains antioxidants that protect the oil rich kernel (45–55% oil) from atmospheric O₂ so preventing it from becoming rancid. The testa and kernel are enclosed in a hard inedible endocarp and a fleshy mesocarp and epicarp, which are light brown and open when they are ripe.

Harvesting

As the nut matures there is a colour change of the exocarp, which is green when the nut is not mature and then progresses through ivory to rose with fully mature (Labavitch 2002). When fully mature, the nut with its shell will be ejected from the hull when pressure is applied with the thumb and forefinger at the hull's distal end (Ferguson *et al.* 1995). Trees are shaken by hand for young trees, mechanically for mature trees and the nuts are caught on canvas sheets or a catching frame and transferred to bins in order to eliminate problems caused by contact with the soil (Labavitch 2002).

Storage

Once they have been dried, nuts can be stored at 20 °C and 65–70% r.h. for up to a year (Ferguson *et al.* 1995). Maskan and Karatas (1998) found that storage at 0–10 °C in less than 0.5% O₂ improved flavour stability as well as insect control. Vacuum packaging, nitrogen flushing and airtight packaging are used because kernels readily absorb moisture and O₂ from the air, so becoming limp and rancid.

Diseases

Postharvest infection with *Aspergillus flavus* can produce aflatoxin and Doster and Michailaides (1994) found that in California early split nuts had over 99% of the aflatoxin detected and navel orange worm

(*Amyelois transitella* Walker), infected nuts had substantially more infection by several *Aspergillus* spp. as well as over 84% of the aflatoxin detected.

Pondicherry sweetpotato

Dioscoreaceae

Dioscorea purpurea Roxb. Sturtevant (1892) wrote 'East Indies. The Pondicherry sweetpotato is known only in a cultivated state and was brought to India from the Mauritius, where it is much grown. The tuber is of a dull, crimson-red outside and a glistening white within'. Coursey (1967) stated that the name *D. purpurea* has been used for some forms of *D. alata* that have tubers with purplish flesh.

Potato

Solanaceae

Solanum tuberosum L. Hawkes (1990) reported that *S. stenotomum* Juz. and Buk. could have been the original cultivated species. Maxted and Kell (2009) reported that *S. tuberosum* is the only cultivated tetraploid ($2n = 48$) of the genus *Solanum* but its wild relatives range from diploid ($2n = 24$) to hexaploid ($2n = 72$). The other cultivated *Solanum* species are the diploids ($2n = 24$), *S. stenotomum* Juz. and Buk. *S. phureja* Juz. and Buk. and *S. ajanhuiri* Juz. and Buk., the triploids ($2n = 36$), *S. chaucha* Juz. and Buk. and *S. juzepczukii* Buk. and one pentaploid ($2n = 60$), *S. curtilobum* Juz. and Buk. Other common names include batata, English potato, Irish potato, papas, patatas, pomme de terre and white potato.

Wild potato occur in a wide variety of habitats, including the high altitude Andean grasslands, dry deciduous forests in Mexico, strand vegetation along Chilean beaches and cool upland rain forests in the eastern Andes (Hijmans *et al.* 2002). Potatoes were said to have been first cultivated around Lago Titicaca at a height of about 3000 m on the borders of Perú and Bolivia, but the anthropologist Ángel in 1970 reported fossils in Chilca in Perú. Farías in 1976 claimed that they have been cultivated for about 8000 years (Gomez Granados and Ramirez Fajardo 1999). The cultivation of traditional potato cultivars of *S. tuberosum* subspecies *andigena* is most widespread in the highlands of Venezuela, Colombia, Ecuador, Perú,

Bolivia and northern Argentina and to a lesser extent in Mexico and Guatemala, primarily at altitudes of 2000–4000 m. The cultivation of other species is more restricted. Cultivation of ancient cultivars of *S. tuberosum* subspecies *tuberosum* is restricted mainly to the Chiloe Island in southern Chile at about sea level (Huamán *et al.* 1997). *S. stenotomum*, *S. gonicalyx* and *S. x chaucha* are primarily cultivated from northern Peru to central Bolivia between 3000 and 3900 m. *S. phureja* is the only species cultivated in the warmer Andean valleys of Venezuela, Colombia, Ecuador, Peru and Bolivia from 2000 to 3700 m, while cultivation of other species is rarer and scattered and may have resulted from recent introductions. The hybrids *S. x curtilobum*, *S. x juzepczukii* and *S. x ajanhuiri* are cultivated in restricted areas of Peru, Argentina and Bolivia at 3800–4200 m (Huamán *et al.* 1997).

When Europeans arrived in America they encountered new crop plants many of which were successfully introduced into Europe. The Spanish conquistadors found potatoes being cultivated in Perú and all along the cordillera of the Andes mountains. The expedition of Gonzalo Jiménez de Quesada reported that in April 1537 they encountered potatoes in Sorocotá, a Chibcha town on the Suarez River in the west of Moniquirá in what is modern Colombia. He wrote: 'Las comidas de esta gente son las de otras partes de indias y algunas más, porque su principal mantenimiento es maíz y yuca, sin esto tienen dos o tres maneras de plantas de que se aprovechan mucho para su mantenimiento, que son unas a manera de turmas de tierra, que llaman Yomas y otras a manera de nabos que llaman cubios, que echan en sus guisados y les es grande mantenimiento' (Epitome del Nuevo Reino de Granada, 1920, quoted by Gomez Granados and Ramirez Fajardo 1999). The British, through their colonies, helped to distribute potatoes around the world.

Woolfe (1987) described potatoes as 'a cheap, nutritious, easily grown food supply'. World production of potatoes has shown a very wide fluctuation over the past 30 years or so but there was a steady increase over the 50 years from 1961 to 2011 (Table 96). The mean yield of potatoes has gradually increased over the last 50 years (Table 97) but in 2011 the mean yield in developing countries was 13.0 tonnes ha⁻¹ compared to 32.1 tonnes ha⁻¹ in the European Union. Production in developed countries, which is much

Table 96 World production of potatoes in million tonnes and mean yield in tonnes per hectare (source: adapted from FAO 2013)

Year	1961	1971	1981	1991	2001	2011
Production (million tonnes)	270.5	279.5	267.8	257.5	311.2	374.4
Mean yield (tonnes ha ⁻¹)	12.2	13.7	14.3	14.6	15.8	19.5

Table 97 The composition of potato tubers for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	General	Russet	White	Red
Water (g)	79.34	78.58	81.58	80.96
Energy (kcal)	77	79	69	70
Protein (g)	2.02	2.14	1.68	1.89
Total lipid (fat) (g)	0.09	0.08	0.10	0.14
Carbohydrate, by difference (g)	17.47	18.07	15.71	15.90
Total dietary fibre (g)	2.2	1.3	2.4	1.7
Sugars, total (g)	0.78	0.62	1.15	1.29
Calcium (mg)	12	13	9	10
Iron (mg)	0.78	0.86	0.52	0.73
Magnesium (mg)	23	23	21	22
Phosphorus (mg)	57	55	62	61
Potassium (mg)	421	417	407	455
Sodium (mg)	6	5	16	18
Zinc (mg)	0.29	0.29	0.29	0.33
Total ascorbic acid (mg)	19.7	5.7	19.7	8.6
Thiamine (mg)	0.080	0.082	0.071	0.081
Riboflavin (mg)	0.032	0.033	0.034	0.031
Niacin (mg)	1.054	1.035	1.066	1.149
Vitamin B-6 (mg)	0.295	0.345	0.203	0.170
Folate (µg_DFE)	16	14	18	18
Vitamin B-12 (µg)	0.00	0.00	0.00	0.00
Vitamin A (µg_RAE)	0	0	0	0
Vitamin A (IU)	2	1	8	7
Vitamin E (α-tocopherol) (mg)	0.01	0.01	0.01	0.01
Vitamin D (D2 + D3) (µg)	0.0	0.0	0.0	0.0
Vitamin D (IU)	0	0	0	0
Vitamin K (phylloquinone) (µg)	1.9	1.8	1.6	2.9
Fatty acids, total saturated (g)	0.026	0.026	0.026	0.035
Fatty acids, total monounsaturated (g)	0.002	0.002	0.002	0.003
Fatty acids, total polyunsaturated (g)	0.043	0.043	0.043	0.059

greater than in developing countries, has tended to fluctuate widely over this period giving the above effect. Despite this fluctuation, world production has remained relatively constant inspite of the distinct downward trend in production in developed countries. In the United Kingdom there were some 80,000 potato farmers in 1960 but less than 10,000 in 1998 (Walker 1998) and the area under production halved during that period from some 280,000 ha in 1960. In the 12 older members of the European Union the area under potatoes fell from 1554 million ha in 1991 to 1450 million ha in 1996. Only the expansion to 15 members kept 1996 production up to approximately 1991 levels. The low prices in 1996/1997 reduced 1997 plantings still further to around 1423 million ha. Even so the potato starch industry expanded its contract area in 1996 as the European Union was using 1996 as the reference year for national starch quotas. All the main EU producing countries showed reductions in the number of growers and increases in average acreage per grower (Graff and Zilberman 2004).

However, the production in developing countries has shown a constant and consistent increase. This increase is largely due to the introduction, by organizations like the International Potato Center (CIP) in Perú, of new cultivars which yield well in the lowland tropics. In the lowland areas of Trinidad in the late 1960s trials carried out at the University of the West Indies produced yields of only some 4 tonnes ha⁻¹. This was on plantings where 2 tonnes of seed per hectare were used. So with these very poor yields, potatoes could be more cheaply imported from countries such as Canada and Holland than grown locally. Burton (1989a) mentioned that a peasant grower in the Andes or the Himalayas could be producing perhaps 5–10 tonnes ha⁻¹ while growers in Europe or North America could be producing 50 tonnes ha⁻¹. Walker (1998) reported that in the United Kingdom in the 1960s average yields were 25 tonnes ha⁻¹ while in 1998 they had risen to 45 tonnes ha⁻¹.

In the past cultivars have been bred and selected to yield well and be resistant to diseases encountered in temperate countries where the temperatures are cooler and day-length more variable than in developing countries. There have also been changes in the eating habits in developing countries where potatoes have been replacing traditional starch staples, largely in urban areas. This is in contrast with the United Kingdom where over the period between 1987

and 1997 'in-home' potato consumption dropped by 27% on a per capita basis. Over the same period the 'in-home' consumption of frozen potatoes rose by 68% and other processed potatoes by 60%. Fresh potato consumption was shown to be high in households with low incomes and where there are older people and lower in more affluent households, households with children and generally younger households (Walker 1998).

Botany

It is an herbaceous perennial usually up to about 100 cm high. It has small white flowers and the fruit is a spherical green or purplish berry about 1.5–2 cm in diameter. Each fruit contains from 50 to 600 minute seeds. Some cultivars rarely, if ever, produce full flowers; others produce flowers with fruits with sterile seed while others produce flowers that set fruits with viable seed. Flowering and fruit set in potatoes are favoured by cool long days. The roots are numerous, fine, fibrous and adventitious. Short stolons with hooked tips are produced from the axils of the lower leaves and become thickened to form stem tubers. When the aerial part of the plant (the haulm) dies back the tubers remain and sprout to form new plants when the dormancy of the tuber breaks and climatic conditions are favourable. The edible portion is these swollen stem tubers that are borne on the ends of stolons. The potato tuber is a modified stem structure, which usually develops below ground as a consequence of the swelling of the sub-apical portion of the stolon with the simultaneous accumulation of food reserve material (Coleman 1987). With further development, the tuber gradually assumes the characteristic shape of the cultivar. Tubers are capable of further growth under suitable conditions to form sprouts. They show all the basic stem morphology with the presence of leaves and axillary buds that are much reduced, have shortened internodes and a radially expanded stem axis (Cutter 1978). The end of the tuber, comprising the original stolon apex, is usually referred to as the *rose end* or *bud end*, while the site of attachment to the stolon is the heel end or stem end. Leaves derived from the stolon apex are arranged in a spiral pattern and their associated axillary buds are referred to as *eyes* (Reeve 1954). Each eye consists of a main bud and an axillary bud associated with the two oldest leaves formed by the main axillary bud

(Cutter 1978). The eyes of each tuber may be shallow, medium or deep in relation to the surface of the tuber (Burton 1989a). This is an important cultivar characteristic since where the eyes are shallow; the peeling losses are usually less during processing or domestic preparation.

Potatoes are propagated from these tubers. This has led to the transmission of diseases. Potato blight was thought to have been introduced to Europe from tubers imported from Mexico and then introduced to Africa and other countries in seed tubers imported from Europe and the Americas. Production from true potato seeds occurs in parts of Africa, Asia and South America. True potato seed are free from fungal and bacterial diseases, nematodes and insect pests, but some viruses are transmitted in true potato seed. Jones (1982) showed that potato tricho virus (PVT) is readily transmitted through true potato seed and pollen and spreads to tubers produced by infected plants.

Chemical content

Tubers will freeze at about -1.8 to -1.7°C (Wright 1942) or -1.44 to -0.83°C (Weichmann 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 97.

Dry matter

The average dry matter of mature tubers was shown to vary over the range 20–36% (Burton 1989a). The percentage dry matter in the tubers increases as they develop and mature (Thompson 1970b, Burton 1989a), but it is different in different parts and can change during storage. Tubers of the cultivars Russet Burbank and Shepody, grown in Canada, were measured to determine variability within tubers. Dry matter was generally higher at the apical and stem ends than in the middle section and was significantly higher in the outside than in the inside of the tuber. There was more variability in dry matter within Shepody tubers than those of Russet Burbank. The outer section of the tuber at the centre of the longitudinal axis was, overall, most highly correlated to the dry matter of the entire tuber for both cultivars and would be the most appropriate single location for estimating the dry matter of the entire tuber. During 6 months storage specific gravity did not change (Pritchard and Scanlon 1997).

Starch

Potato starch contains both amylose and amylopectin at a fairly constant ratio 1:3. Starch is synthesized in the specialized leucoplasts, which are called amyloplasts or starch grains, located in the cytoplasm mainly of the parenchyma cells of the tubers. These amyloplasts are surrounded by a double membrane and contains starch-synthesizing enzymes. The double membrane, while it remains intact protects the starch from degrading enzymes (Shekhar *et al.* 1979). As the crop matures its percentage dry matter increases and at the same time the percentage of starch in the dry matter also increases as does the size of the individual starch grains up to $100 \times 70 \mu\text{m}$ or more (Burton 1989a). Starch is laid down in concentric shells possibly from periodic deposition of starch giving an oval grain. The percentage starch in the tuber increased during development similarly to dry weight while the sugar content decreased (Table 98). Studies of transgenic potato plants with sense and antisense copies of the potato D-enzyme (disproportionating enzyme or 4α -glucanotransferase; EC 2.4.1.25) did not indicate a direct requirement for D-enzyme in the synthesis and accumulation of storage starch in tubers (Takaha *et al.* 1998).

Sugars

Sugars in tubers consist mainly of glucose, fructose and sucrose, which comprise some 3% of the dry weight and 0.6–0.7% of the fresh weight of mature tubers (Kolbe 1996). In a study of two cultivars by Pritchard and Scanlon (1997) they found that the sucrose concentration generally decreased from the stem end to the apical end of the tuber in Russet Burbank but increased from the stem end to the apical end in Shepody. Sucrose, glucose and fructose were generally greater, though not always significantly, in the inside of the tuber compared with the outside with the exception of sucrose in Shepody where it was

somewhat higher in the outside section. Glucose and fructose generally decreased from stem end to apical end although the difference between the two ends was significant only in Shepody.

A dynamic mathematical model based on underlying physiological processes was developed to describe, analyse and predict the storage behaviour of potato tubers in terms of accumulation of reducing sugars. The data necessary for calibration and validation of the model were gathered during long-term storage experiments over a wide range of storage temperatures for several seasons and cultivars. Although the model is based on a considerable simplification of the occurring physiological processes, it is capable of accounting for about 95% of the storage behaviour, including both cold-induced and senescent sweetening. The concept is postulated that the state of maturity at the time of harvest determines storage behaviour through the initial amount of enzyme (or enzyme system) responsible for cold-induced sweetening (Hertog *et al.* 1997). Khanbari and Thompson (1996) showed that the gaseous environment in the store and the storage temperature and could affect the sugar content of the tubers, but this affect varied between cultivars (Table 99).

Protein

Okeyo and Kushad (1995) evaluated the cultivars Atlantic, BelRus, Kennebec and Superior for soluble protein contents at harvest, after 6 weeks of storage at 3°C and after 2 weeks of reconditioning at 25°C . At harvest soluble protein contents varied among the cultivars, with Superior containing the highest amount 46.4 mg g^{-1} dry weight. Soluble protein content of Atlantic and Superior was not influenced significantly by cold storage or reconditioning, but BelRus and Kennebec had less protein after reconditioning.

Alkaloids and glycoalkaloids

The limit for safe human consumption of α -ne, α -chaconine and total glycoalkaloids was given as 200 mg kg^{-1} f.w. (Tan and Haynes 1996). The total level of glycoalkaloids was shown to vary widely among cultivars. In line WB8003-3, which was bred from *S. acaule* and *S. phureja*, some glycoalkaloids, including α -solanin, were not present and did not appear following illumination (Mori and Kozukue 1995). Storage environment and storage time can

Table 98 Dry matter, starch and sugar levels of Irish Cobbler potato tubers at different stages of development. (Source: Burton 1989a)

Physiological stage	Dry matter (%)	Starch (%)	Sugar (%)
Flowering	16	64	4.8
End of flowering	17	66	5.2
Leaves decline	19	72	2.9
80% leaves dead	21	73	0.8
100% leaves dead	20	72	0.7

Table 99 Sugars (g 100 g⁻¹ dry weight) in tubers of three potato cultivars stored for 25 weeks under different controlled atmospheres at 5 and 10 °C and reconditioned for 2 weeks at 20 °C (source: adapted from Khanbari and Thompson 1996)

Cultivar	Gas combinations		5 °C		10 °C	
	O ₂	CO ₂	Sucrose	Reducing sugars	Sucrose	Reducing sugars
Record	3.6	9.4	0.76	0.22	0.91	0.49
Record	3.6	6.4	0.76	0.35	1.39	1.14
Record	3.6	3.6	0.62	0.53	1.60	0.75
Record	3.6	0.4	0.79	0.51	0.65	0.52
Record	21.0	0.5	0.32	0.73	1.00	0.63
Saturna	3.6	9.4	0.90	0.32	0.69	0.23
Saturna	3.6	6.4	0.33	0.61	0.64	0.24
Saturna	3.6	3.6	0.44	0.38	0.73	0.36
Saturna	3.6	0.4	0.29	0.22	0.80	0.12
Saturna	21.0	0.5	0.22	0.62	0.79	0.41
Hermes	3.7	9.4	0.37	0.48	0.26	0.22
Hermes	3.7	6.4	0.22	0.33	1.36	0.47
Hermes	3.5	3.6	0.49	0.74	0.88	0.27
Hermes	3.6	0.4	0.29	0.43	0.59	0.30
Hermes	21.0	0.4	0.70	0.93	0.62	0.51

affect glycoalkaloid content of tubers. Alpha, King Edward, Cara, Jearla and Cluadia tubers were stored for 90 days at 7 °C and 95–98% r.h. or in a Nawala (a ventilated storage house with variable temperature and humidity). In all cultivars and both storage environments the α -chaconine and solanine contents fluctuated but were generally lowest after 60 days and tended to increase towards the end of the storage period. Storage at 7 °C and 95–98% r.h. resulted in lower α -chaconine and solanine than tubers stored in a Nawala (Abdel Gawad *et al.* 1992).

The use of γ -irradiation to control sprouting and increase the length of storage time of potatoes has been proposed as an alternative to cold storage or the use of chemical sprout suppressants. The effects of different levels of γ -irradiation on seven potato cultivars were investigated in relation to chlorophyll and glycoalkaloid synthesis on subsequent exposure to light after a period of storage. There were significant genotype differences between cultivars in their response to γ -irradiation, with some cultivars exhibiting dramatically reduced levels of glycoalkaloid synthesis compared with others. Also, cultivars responded differently to variable irradiation levels. The implications of the results are discussed in relation to public health concerns and selection within potato breeding programmes (Dale *et al.* 1997).

Tubers from six potato cultivars were placed into either 10 or 4 °C stores immediately postharvest.

Replicated tuber samples were analysed for glycoalkaloid content immediately postharvest, after 6 and 14 weeks storage at 10 °C and after 6 weeks storage at 4 °C. Subsamples from the 10 °C store were removed after 1, 2, 3, 4 and 8 weeks, respectively, stored for a further 6 weeks at 4 °C, and again analysed for glycoalkaloid content. After each sampling date, tubers were exposed for 96 h to light and analysed for both chlorophyll and glycoalkaloid concentrations. The exposure of tubers from some cultivars, such as Brodick and Pentland Crown, to low temperatures within 2 weeks of harvest resulted in a relatively rapid accumulation of glycoalkaloids to levels close to or exceeding the recommended safe maximum level of 200 mg of glycoalkaloid kg⁻¹ f.w., while other cultivars, such as Eden and Torridon, appeared insensitive to cold stress. Storage for 6 weeks at both 10 and 4 °C resulted in a greater accumulation of glycoalkaloids in response to light exposure relative to that observed immediately postharvest, with the tubers from all six cultivars stored at 4 °C producing over twice the amount of glycoalkaloid as those stored at 10 °C. Storage at 10 °C prior to 6 weeks storage at 4 °C resulted in smaller photo-induced increases in glycoalkaloid content but even after 8 weeks at 10 °C followed by 6 weeks at 4 °C, the photo-induced increases in all cultivars were significantly higher than that recorded for tubers stored continually at 10 °C, which had

values comparable to those obtained immediately postharvest. In all cultivars, photo-induced chlorophyll accumulation was little affected by storage temperature but was slightly, although significantly, reduced as time in storage increased from 6 to 14 weeks. The significance of these results in relation to consumer safety and plant breeding is discussed (Griffiths *et al.* 1998).

A study was conducted to develop a simple, rapid and inexpensive immunoassay for potato glycoalkaloids that correlates with HPLC. This was successfully demonstrated with various potato samples, including eight fresh potato cultivars; potato flesh, peel, sprouts and leaves and processed products such as French fries, chips and skins. Storage of the ELISA kit in a refrigerator for greater than 3 months did not affect its effectiveness. The use of a stable, accurate, and highly sensitive ELISA kit should facilitate (i) development of standard protocols for handling and sampling of potatoes to minimize pre- and postharvest glycoalkaloid formation; (ii) analysis of foliar glycoalkaloids, thus saving plant breeders considerable time, effort and cost; (iii) marketing potatoes at lower cost; (iv) measurement of the metabolism and distribution of glycoalkaloids in animals and humans and (v) assurance to the consumer of eating a good quality potato (Friedman *et al.* 1998).

Greening

The accumulation of glycoalkaloids in tubers is commonly associated with chlorophyll synthesis (greening). The cultivars Pentland Dell and Record tubers were treated with the chlorophyll biosynthesis inhibitors 4-amino-5-fluoropentanoic acid and 3-amino-2,3-dihydrobenzoic acid (gabaculine), and subsequently exposed to daylight for up to 10 days prior to pigment and glycoalkaloid analysis. 4-Amino-5-fluoropentanoic acid inhibited the accumulation of total chlorophyll by between 50 and 70% in both cultivars throughout the duration of light exposure. The synthesis of chlorophyll b was inhibited by over 80% in both cultivars. Neither inhibitor had a significant effect on light-enhanced glycoalkaloid accumulation. It was concluded that there was no direct metabolic link between chlorophyll and glycoalkaloid biosynthesis (Edwards *et al.* 1998). However light appears to be involved in glycoalkaloids synthesis in stored tubers. In tubers of eight potato lines and cultivars the levels of several

glycoalkaloids, including solanin, increased when the tubers were exposed to strong light (Mori and Kozukue 1995). The association between greening and glycoalkaloid level in tubers may be one of light affecting two unrelated and independent biosynthetic processes. This hypothesis is confirmed by experiments described by Edwards and Cobb (1997). Tubers of King Edward were stored at 5, 10, 20 or 25 °C for up to 8 days in either low light or darkness. Tubers were half buried in potting compost to prevent light reaching the entire tuber surface. After 0, 2, 5 and 8 days, samples were analysed for photosynthetic pigment and glycoalkaloid content. Greening in tubers was highest at 20 °C. The buried surface of tubers exposed to light also greened, although accumulating only 15–40% of the chlorophyll found in the upper, exposed tissues. However, there was no effect of the temperature or light exposure regimes employed on glycoalkaloid concentrations.

The effects of light on greening and visual external quality of tubers of the cultivars Atlantic and Cadima which had been coated with various protective coating solutions (3% sweetpotato flour, 3% tapioca flour, 3% arrowroot flour, 3% gelatin, 1.5% Semperfresh and LDPE bag) were investigated. Gelatin solution coating reduced the degree of greening and hence improved the tuber quality when they were placed under constant light (Tan and Haynes 1996). The maturity of the tubers based on harvesting date seemed to have no effects on the development of greening in Atlantic and Cadima, but the degree of greening was more severe in Atlantic than in Cadima. The contents of α -solanine, α -chaconine and total glycoalkaloids were also determined and found to be well below the 200 mg per kg FW limit for safe human consumption. No apparent trends were observed when comparing potatoes harvested at different maturity and stored under light after different coating treatments (Tan and Haynes 1996).

Ascorbic acid

Sikora and Miedzybrodzka (1989) stored potatoes of the strain WOC 2083 in different conditions at temperatures from 4 to 16 °C for up to 6 months. The initial contents of vitamin C were 14.11 mg 100 g⁻¹ with losses during 6 months of storage of about 70%. Okeyo and Kushad (1995) evaluated the cultivars Atlantic, BelRus, Kennebec and Superior for ascorbic acid content at harvest, after 6 weeks storage at 3 °C

and after 2 weeks reconditioning at 25 °C. At harvest, ascorbic acid varied among the cultivars, with Superior containing the highest amount of ascorbic acid (154 mg 100 g⁻¹ dry weight). Cold storage resulted in a $\pm 50\%$ reduction in ascorbic acid content in all four cultivars. Ascorbic acid also decreased during reconditioning of tubers, but the reduction was less than during cold storage.

Acrylamide

Acrylamide is produced in starchy foods such as potatoes that are baked, roasted or fried at high temperatures but not those that had been boiled or have not been heated (Tareke *et al.* 2002). Concerns about the potential health issues associated with the dietary intake of acrylamide were reported by Mottram *et al.* (2002). Storage at 4 °C compared to 8 °C appeared to enhance acrylamide formation due to a strong increase in reducing sugars that are precursors. Because the synthesis of acrylamide is reversible it was possible to achieve a significant reduction of the reducing sugars after reconditioning tubers for 3 weeks at 15 °C. There appears to be a cultivar susceptibility to acrylamide synthesis. Saturna, mainly used in crisp production, appeared to be the least susceptible to acrylamide formation during frying. The use of a sprout suppressant did not influence acrylamide formation (De Wilde *et al.* 2005).

Preharvest factors

As well as the appropriate climatic conditions the success of commercially producing and marketing potatoes depends on a combination of the most appropriate factors that include cultivar, soil conditions and fertilizer application in addition to pest, disease and weed control.

Cultivars

There is a whole range of cultivars. Most have been bred to produce the highest yields in temperate long day conditions such as those found in Europe. Storage life varies between cultivars that are related to natural dormancy, skin quality and texture, moisture content and susceptibility to pests and diseases.

Fertilisers

The application of fertilizers to the growing crop not only affects the yield but also the quality, harvesting and postharvest characteristics of the tubers. For

example the maintenance of sensory quality of tubers was shortened by high amounts of N and K fertilizers and when tubers were harvested immature (Ahvenainen *et al.* 1998). However, Putz and Lindhauer (1994) found that N, P, K, Ca and organic fertilizers had negligible effects on reducing sugar content of tubers in long-term field trials.

Grzeskiewicz *et al.* (1985) found that the doubling of the NPK level from 315 to 630 kg ha⁻¹ resulted in an increase of the mechanical damage index and of the proportion of damaged tubers. However, under commercial field conditions it was found impossible to prove the statistical significance of the differences. There was a significant effect of the negative influence of the high NPK rate on losses after 6 months of storage in clamps. Kolbe *et al.* (1995) found that after high NK fertilization most tubers had higher water content at harvest time than those with low levels and weight losses were increased after N and K application and decreased by increasing P application. They also found that at harvest, the glucose and fructose contents in tubers were reduced by high K fertilizer rates compared to low or absence of fertilizers, but throughout storage, reducing sugar accumulation increased, sucrose reduction decreased and ascorbic acid content increased. Loss of the tuber fresh weight and dry matter content during storage increased with fertilizer rate but loss of starch was high only at high N rates. The highest N (200 kg N ha⁻¹) and K (320 kg K₂O ha⁻¹) rates had a negative effect on the organoleptic properties of tubers, especially after 6 months of storage (Rogozinska and Pinska 1991).

Potassium

There is compelling evidence of a significant reduction in susceptibility of tubers to damage with increasing rate of application of K fertilizer. However, the effect is not large and is primarily observed for the K deficient range of concentrations (McGarry *et al.* 1996). In a field experiment by Singh *et al.* (1996) tubers were given 0 to 180 kg K₂O ha⁻¹ and when tubers were stored for 14 weeks losses and sprouting were the lowest where 180 kg K₂O had been applied. In contrast Sharma and Ezekiel (1993) found that sprout weight was increased with K₂O application after 60 days of storage but tuber weight loss and sprouting were not affected. They also found that dry matter, ascorbic acid and total sugar content of tubers

increased with the application of K_2O . Panique *et al.* (1997) reported a reduction in specific gravity with increasing applied K in most of the site and years and a significant decrease in hollow heart with increasing rate of K fertilizer application was observed in 4 of 11 site years. They also reported that the incidence of *Rhizoctonia solani* was generally not affected by K rate, but there was a tendency in some site years for a higher disease incidence when KCl was used instead of K_2SO_4 (Panique *et al.* 1997). Kolbe *et al.* (1995) found that at harvest, the glucose and fructose contents in tubers were reduced by high K fertilizer rates compared to low or absence of fertilizers, but throughout storage, reducing sugar accumulation increased, sucrose reduction decreased and ascorbic acid content increased. Badshah *et al.* (1990) found that K fertilizer had a negative effect on tuber quality only at rates above 240 kg ha^{-1} .

Nitrogen

Increasing levels of N fertilizer application did not increase the susceptibility of tubers to mechanical damage (Divis and Sterba 1997). Rogozinska and Pinska (1991) found that loss of the tuber FW and DM content during storage increased with fertilizer rate but loss of starch was high only at high N rates (200 kg N ha^{-1}). The highest N and K rates ($320 \text{ kg K}_2\text{O ha}^{-1}$) had a negative effect on the organoleptic value of tubers, especially after long-term (6 months) storage. Potatoes grown with high levels of N had lower amounts of free sugar at all times (Roe *et al.* 1990). High N levels delayed tuber formation resulting in more immature tubers when harvested at the same time as tubers grown with lower N levels (Bodin 1988). Admiraal (1988) found that tuber density was less with in tubers grown in 150 kg N ha^{-1} applied 4 weeks after harvest and after 3 months storage at 10°C compared with those grown without N fertilizer. Van Ittersum (1992) showed that an increased N rate at planting resulted in a shorter dormancy when the duration of dormancy was expressed in days after tuber initiation, but not when it was expressed in days after haulm destruction, probably because extra N also delayed tuber initiation. Kolbe *et al.* (1995) found that high N also resulted in an increase in pectic substances and lower cellulose content. During storage at 4°C and 90% r.h. there was an increase in water loss of 54% as a result of N fertilization. Kolbe *et al.* (1995) found that at harvest, the glucose and

fructose contents in tubers were reduced by high N fertilizer rates compared to low or absence of fertilizers, but throughout storage, reducing sugar accumulation increased, sucrose reduction decreased and ascorbic acid content increased. N decreased reducing and non-reducing sugars content after storage for 3 months at 10 or 15.5°C (Badshah *et al.* 1990).

Phosphorus

Little information exists in the literature on the effects of field application of P fertilizers on the postharvest life of tubers. Kolbe *et al.* (1995) found that increasing levels of P fertilizer during growth resulted in decreased weight losses during storage at 4°C and 90% r.h. for 6 months. Phosphorus levels in tubers were reported to be 0.093% by Banks and Greenwood (1959).

Calcium

Paiva *et al.* (1997) found the plantlets grown in nutrient solution with seven different Ca concentrations between 0 and 972 mg Ca L^{-1} , the tuber quality during storage for 6 months at 25°C was greatly increased in tubers that had been grown in the highest Ca concentrations. In a 3-year study with three cultivars by Clough (1994) on a fine sandy loam soil 0, 90, 180 or $270 \text{ kg Ca ha}^{-1}$ as CaSO_4 was applied before planting, and/or 0, 34 or 68 kg Ca ha^{-1} as $\text{Ca}(\text{NO}_3)_2$. After 4 months of storage at 7°C , severity and percentage of tubers with internal brown spot were reduced by Ca application either before planting or as a side dressing.

Magnesium

The influence of Mg and Ca in the cell wall and middle lamella on resistance to diseases was studied in two genotypes with large differences in their levels of resistance. Increased content of Mg, especially in the periderm and cortex, improved resistance to *Phoma exigua* var. *foveata* but not to *Fusarium solani* var. *coeruleum*. The effect of Mg was greater than that of Ca and the results indicated that the ratio Mg:Ca might be of importance for resistance to gangrene. This effect can be explained by the pectin-bound Mg that gives a firmer cell wall and middle lamella than the pectin-bound Ca (Olsson 1988).

Micronutrients

In India Shashirekha and Narasimham (1990) found that dipping seed tubers in aqueous solutions

of trace element salts decreased both sprouting and microbial spoilage during storage in ambient conditions.

Harvest maturity

If potatoes are to be stored, then the optimum harvest time is after the leaves and stems have died down. If they are harvested earlier the skins are less resistant to harvesting and handling damage and are more prone to storage diseases. In certain cases where the leaves have not senesced naturally the whole of the tops of the plant, which is called the haulm, may be cut-off or removed chemically or mechanically to produce tubers with firmer and stronger skins before they are harvested. Therefore for main crop potatoes there should be a delay between the haulm dying down and harvesting to allow the periderm to fully form. This reduces the tubers' susceptibility to damage during harvesting and handling. There is variation in periderm formation on different parts of the tuber and between different cultivars. For example Lulai and Orr (1993) found that in all the cultivars they studied that there was lower skin set at the bud end of the tuber compared to the equatorial region and stem end. Also the periderm of Russet Burbank tubers matured more rapidly than the periderm of other cultivars with smooth skins. Bowen *et al.* (1996) showed that no one skin characteristic was related to a stronger skin, except in the case of Record where the strength of the skin was related to its thickness. Differences in skin adhesion strength were poorly related to skin morphological characteristics such as skin thickness, cell size and suberin content. The method of haulm destruction affected skin adhesion strength with skins adhering more rapidly and more strongly to the tuber following haulm pulling compared with either desiccation with chemicals or mechanical flailing. For processing the maturity of tubers at the time of harvest determines the storage behaviour through the initial amount of the enzyme, or enzyme system, responsible for cold-induced sweetening and therefore the colour of the crisps or chips (Hertog *et al.* 1997). On average, tubers from the early planting in the United States had lower respiration rates during curing and emerged from dormancy sooner than those planted later (Knowles *et al.* 2009).

Harvesting methods

The harvesting method and equipment used can affect the amount of damage caused to the tubers, which in turn can affect their postharvest life. Mechanized harvesters remove the crop from the ground either by undercutting it or by inverting the soil ridges in which the crop is grown. Mouldboard ploughs, subsoilers and other tillage tools used in root crop harvesting may require a lot of power to remove them from the soil. Using vibrating digger blades can reduce the power required which varies with the amplitude of the vibration (Kang *et al.* 1993). X-rays were used in prototype potato harvesters to differentiate between the tubers and extraneous matter such as clods of earth and stones (Whitney 1993). The equipment was mounted behind the chain lifter but was found to be impractical because the height of fall of the tubers was too great.

With some machines the crop may be left on the soil surface after harvesting; in others they may be lifted and loaded into a trailer for direct transport to the store or packhouse. Some harvesters have the facility to pack the crop directly in the field into wholesale or retail packs. Normally only early potatoes are lifted and bagged in the field (John Love 1994, quoted in Thompson 1996) while main crop potatoes are taken to the store or packhouse for grading, sometimes cleaning and packing. In the United States mechanical damage occurring at harvest with a mechanical harvester depended on the harvesting conditions (Kundzicz 1985). At later harvest dates with lower temperatures and increased moisture, the amount of damage increased in all cultivars tested. Votoupal and Slavik (1986) found that the degree of mechanical damage incurred during harvesting affected total storage losses. Mechanical damage primarily increased losses because of rotting by up to 75%, but changes in respiratory losses resulting from mechanical damage were small. They quantified the level of storage losses of tubers due to mechanical damage incurred during harvesting. In severely damaged tubers losses mainly due to rotting were 40% for the very early cultivar Ostara, 61% for the early cultivar Karin, 50% for the semi-early cultivar Radka and 75% for the semi-late cultivar Nora. Changes in respiratory losses resulting from mechanical damage were small. In India the crop is harvested 10–15 days following stoppage of last irrigation to allow for the skin to set. This allows tuber skin to become firm and

tubers do not get bruised on harvesting. Harvesting is done manually with the help of spade or *khurpi* or by bullock drawn single row digger/plough. It is also done mechanically with the help of 1–4 row potato digger (Pandey and Sarkar 2005).

Cells of tubers react to damage in various ways. One of them involves the oxidation of phenolic compounds such as chlorogenic acid and caffeic acid (Burton 1989a). A review by McGarry *et al.* (1996) showed that information is available on soil-related factors, particularly potassium fertilizer, for which there is fairly compelling evidence of a significant reduction in susceptibility with increasing rate of application. The relevance of the relationships between internal damage and tuber water status shows strong evidence that it is of major importance. Muir and Bowen (1994) showed that no single skin characteristic was related to skin strength, except in the case of Record where the strength of the skin was always related to its thickness. Only 25% of tubers showed signs of scuffing damage after pulling compared to 34% after chemical desiccation with Diquat and 38% after flailing. Bowen *et al.* (1996) developed a standardized instrumental test of skin set, called a scuff meter and tested it on six cultivars. Using this meter 49 days after haulm destruction, skin adhesion strengths were similar in all cultivars except Record, which had much greater skin adhesion strength. Differences in skin adhesion strength were poorly related to skin morphological characteristics such as skin thickness, cell size and suberin content. The method of haulm destruction affected skin adhesion strength with skins adhering more rapidly and more strongly to the tuber following haulm pulling compared with either desiccation with Diquat or mechanical flailing. The method of haulm destruction did not influence skin morphological characteristics.

Storage conditions can affect the development of damage. For example there was a significant reduction in mechanical damage to tubers stored at 9 °C compared with 4.5 °C (Divis and Sterba 1997). Pressure bruising can occur where tubers are compressed, distorted or crushed. This damage may also be a function of time, especially where the pressure is close to the threshold value. It may be as a result of overfilling boxes and then stacking the boxes so that the crop in the lower boxes supports the weight. It is also commonly found in the lower layers of

potatoes in bulk stores. There are differences between cultivars in their susceptibility to compression damage. It may also be related to their moisture content, the higher their moisture content the more they are susceptible, which, in turn, may be related to pre-harvest cultural effects. Lulai *et al.* (1996) found that in pressure-bruised areas the suberized phellem were damaged or completely flattened and a layer of what appeared to be crushed cells was often detected beneath the pressure-bruised, but partially intact, phellem.

Pre-cooling

Potatoes are rarely precooled, but forced air cooling with high humidity was the most acceptable for new potatoes, air cooling in a conventional cold store was suitable and hydrocooling and vacuum cooling were said to be less suitable (MAFF n.d.). Hydrocooling could lead to bacterial rots and vacuum cooling would be so slow and expensive as to be irrelevant. However, Holmes and Kemble (2009) recommended forced-air cooling, hydrocooling or room cooling for potatoes grown in the southern United States.

Postharvest changes

Respiration

The cultivars Pentland Dell and Record were stored at 95% r.h. and at 5 and 10 °C in darkness for 40 weeks during successive years. The respiration rate was measured and the general trend was similar at both temperatures; that is an initial decline to basal rates followed by an increase associated with the breaking of dormancy and initiation of sprouting (Williams and Cobb 1992). Respiration rate of tubers was low in main crop potatoes since they are natural storage organs and are dormant when harvested at full maturity (Table 100). Generally low levels of O₂ and high levels of CO₂ reduce respiration rate (Thompson 2010), but in experiments carried out by Robinson *et al.* (1975) storage of main crop in 3% O₂ had no effect on their respiration rate, but it had a slight effect on immature tubers. However, Pal and Buescher (1993) described experiments in which the cultivar Russet was held in air or in 10, 20 or 30% CO₂. Short-term exposure to 20 or 30% CO₂ resulted in an increased respiration rate. At 4 °C Hartmans *et al.* (1990) showed that tuber respiration

Table 100 Effects of temperature and reduced O₂ level on the respiration rate in milligrams carbon dioxide per kilogram per hour of potatoes (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	In air					In 3% O ₂		
	0	5	10	15	20	0	10	20
Main crop (King Edward)	6	3	4	5	6	5	3	4
New (immature)	10	15	20	30	40	10	18	30

rate was lower in 3 or 1% O₂ compared to those in air and in 35% O₂. Inaba *et al.* (1989) found that there was increased respiration in response to ethylene at 100 µl L⁻¹ for 24 h at 20–35 °C, but the effect was much reduced at lower temperatures. Voss (2002) reported that immature potato tubers usually have higher respiration rates than mature or cured tubers (Table 101).

Production of ethylene by potato tubers was less than 0.1 µl kg⁻¹ h⁻¹ (Knee *et al.* 1985) or in the range less than 5 × 10⁻⁴ µl kg⁻¹ h⁻¹ to 3 × 10⁻¹ µl kg⁻¹ h⁻¹ for the cultivar Russet Burbank, with higher levels associated with the onset of sprouting, physiological breakdown and following pathogen inoculation (Creech *et al.* 1973). Wills *et al.* (2003) reported concentration of about 0.04 µl L⁻¹ ethylene in cartons of potatoes in a wholesale market. Ethylene was shown to increase the respiration rate of potatoes

Table 101 The effects of maturity on the respiration rates in milligrams carbon dioxide per kilogram per hour of potato tubers at different temperatures (source: adapted from Voss 2002)

Temperature (°C)	Immature	Mature (cured)
5	24	6–18
10	30–40	13–19
15	25–57	11–22
20	32–81	14–29

(Reid and Pratt 1970) and Foukaraki *et al.* (2012a) found that exposure of tubers to 1-MCP increased their respiration rate whether or not they had been exposed to ethylene in store.

Chemical changes during storage

The largest constituent of potato tubers is carbohydrate. This is almost entirely starch, but some structural carbohydrates (cellulose and lignin) and sugars are present the latter especially if the weather conditions are cold just before harvest. Also the levels of sugar can change during storage. Barker (1938) stored tubers for over a year at different temperatures and found a very rapid increase in total sugars after only 1 month at 5 °C. At 7.5, 10 and 15 °C increases in sugar levels increased slowly (Figure 48). The sugars are almost entirely sucrose, glucose and fructose. Glucose and fructose were shown to increase and sucrose decrease during storage (Abdel Gawad *et al.*

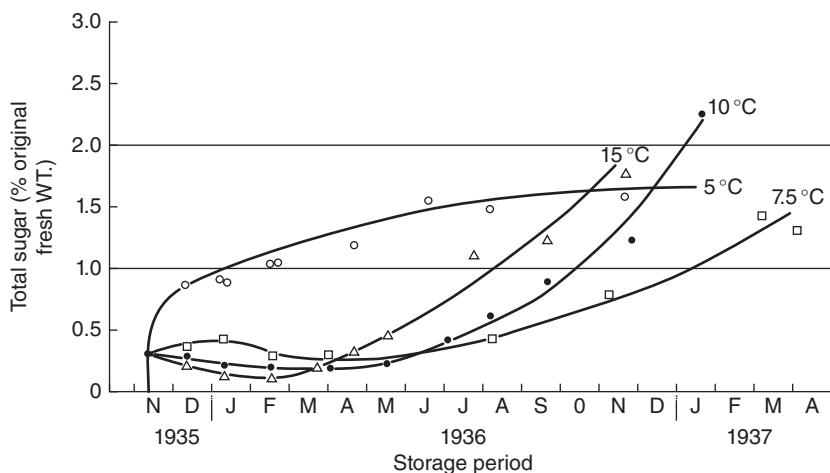


Figure 48 Changes in the sugar content of mature potatoes (cultivar King Edward VII) during prolonged storage at 15 °C (Δ), 10 °C (●), 7.5 °C (□) and 5 °C (○). From Barker (1938) quoted by Burton (1966).

1992). Of course total carbohydrate was also shown to decrease because of respiration. Sugar content and invertase (β -fructofuranosidase) activity were measured in tubers from eight cultivars after 0, 30, 60 and 90 days storage at 5–7 °C by Uppal (1995). Before storage, reducing sugar content ranged from 2.1 mg g⁻¹ f.w. in Kufri Sherpa to 7.5 mg in Kufri Jyoti and sucrose content ranged from 1.7 mg in Kufri Sherpa to 3.0 mg in Kufri Bahar and Kufri Sindhuri. Invertase activity was the highest in Kufri Lalima and the lowest in Kufri Sherpa and it increased during storage.

Long-term studies were carried out by Putz and Lindhauer (1994) of the variations between years and the influence, site, cultivars, fertilizers (N, P, K, Ca and organic fertilizers), harvesting date and temperature of storage on the reducing sugar content of tubers grown for production of chips (French fries) and crisps. Results indicated that cultivar was the most important factor with the upper and lower limits of reducing sugar content genetically determined. Within these limits weather conditions, site, tuber maturity and storage temperature were almost equally important, but there were negligible effects of fertilizers. Bodin (1988) showed that the concentration of reducing sugars in stored tubers of the cultivar Saturna depended on its developmental stage at harvest, cessation of sprouting and storage temperature. Effects of mechanical damage, pressure and short drops in temperature also affected reducing sugar concentration, causing loss of uniformity in tuber quality. Decrease in reducing sugar concentration seemed to be connected with increased gibberellin synthesis at this stage. Storage temperature effects on carbohydrate balance were well recognized but not fully understood. However, tubers harvested at different developmental stages had different storage temperature requirements for keeping reducing sugar concentration low. Increased darkening of crisps normally represented an increase in storage temperature. Anti-sprouting treatments affected parts of tuber metabolic pathways and therefore could affect sugar accumulation.

In freshly harvested mature tubers, a state of dynamic equilibrium exist in which most of the carbohydrate is present as starch (20.3% f.w.). Glucose, fructose and sucrose were present in smaller, roughly similar, amounts (0.13, 0.1 and 0.12% f.w., respectively) (Southgate 1976). The chemical composition

Table 102 Composition of dry matter of potatoes as a percentage of fresh weight (source: adapted from van Loon and Müller 1984)

Starch	9.0–25.0	Amino acids	1.2–2.5
Crude fibre	0.4–1.0	Fat	0.05–0.2
Sugars	0.1–5.0	Organic acids	1.0–3.0
Vitamins	0.01–0.05	Minerals	0.3–1.2
Phenols	0.05–0.4	Alkaloids	0.003–0.011

of tubers varied substantially according to cultivar, conditions during growth and degree of maturity. van Loon and Müller (1984, cited by Harris 1992) gave the chemical composition of dry matter during storage (Table 102). It has been known for many years, however, that in air at low temperatures a marked increase in the sugar content of potato tubers occurred (Müller Thurgau 1882, Burton 1965). The effects of CO₂ and O₂ on the sugar metabolism of tubers have also been studied by many researchers.

Thornton (1939) showed that the reducing sugar content was greatly increased by storage of the tubers at 21 °C in an atmosphere containing 60% CO₂ and that the sucrose was increased with either 30 or 60% CO₂. Barker (1935), whose data were reported only on the basis of total sugars, found that all concentrations of CO₂ used with tubers stored at 5 and 7.5 °C increased the total sugar content. At 1 °C the total sugars were increased by 20% CO₂, but this was accompanied by discolouration and the development of a peculiar odour of the tubers. The results of Denny and Thornton (1941) showed that at 5 °C a concentration of 5% CO₂ retarded the development of reducing sugars to such an extent that at the end of 1 month the amount of reducing sugars of the juice of the CO₂-treated tubers was approximately one-fifth of that of the control in air.

Exposure of the tubers to 95% CO₂ + 5% O₂ for a period up to 7 weeks at low temperature decreased the rate at which reducing sugars accumulated. Workman and Twomey (1970) found that during long-term storage of the cultivar Kennebec, increasing the CO₂ from 0 to 4% boosted the reducing sugar content at 5 °C, but not at 0 °C. On the other hand, Workman *et al.* (1976), using higher levels of CO₂ at 0 and 5 °C, found that increasing CO₂ during storage increased the reducing sugar content and the sucrose.

Burton (1978) came to the following conclusions in a review of the literature: 'Increased CO₂ has been investigated, as a possible means of preventing

the undesirable accumulation of reducing sugars in potatoes held at moderately low temperature. 5% CO₂ has been found to prevent this at 5 °C. Further findings revealed that CO₂ concentrations of 5–20% initially reduced sugar formation at low temperatures, but after a few months' sugar formation increases to such extent that the content is higher than with storage in normal air⁷.

Anaerobic conditions in 100% N₂ reduced or prevented sugar accumulation at low temperature (Harkett 1971). In experiments with higher than normal atmospheric O₂ concentrations, up to 100%, the same author found more sugar formation in the potato tubers than with storage in air. Workman and Twomey (1970) reported that O₂ concentrations of 1–3% are almost as effective as anaerobic storage and also decrease the reducing sugar content at 1 °C. An O₂ level of 5%, however, was much less effective. Reust *et al.* (1984), after storing tubers of the cultivar Bintje at 6% CO₂ and plus 2, 6 or 15% O₂ found a considerable accumulation of sugars, particularly sucrose, at 8 and 10 °C, and cooking quality was seriously affected. In a modified atmosphere of 3% O₂, Parkin and Schwobe (1990) found a reduction in sucrose accumulation at 3 °C and suggested further studies to establish an optimum condition in low O₂ atmosphere. However, Schouten (1992) found a slow increase in glucose when tubers were stored for 6 months at 6 °C in an atmosphere containing 1% CO₂ and 1% O₂.

Cultivars have been bred that have reduced tendency to breakdown starch into sugar. Tubers of the cultivar Norchip, a low-temperature sweetening-susceptible cultivar, and North Dakota 860-2, a low-temperature sweetening-tolerant cultivar, were stored at 4 or 12 °C for 55 days. Sugar accumulation was not linear and was characterized by fluctuations or cycles during storage. Sucrose cycling and accumulation were greatest for Norchip tubers stored at 4 °C. Increases in membrane permeability were not detected by increases in electrolyte leakage. No significant changes in the phospholipid, galactolipid or free sterol levels or phospholipid to free sterol ratio were observed. The double-bond index obtained from the fatty acid profiles of the total lipid fraction decreased significantly (decreased unsaturation) for Norchip tubers at 4 °C during storage. Free fatty acid and diene conjugation values increased in storage for all treatments with greater amplitude of fluctuations

observed for Norchip tubers stored at 4 °C. These latter effects may be due to the high levels of lipid acyl hydrolase and lipoxygenase found in potato tubers. When free fatty acid and diene conjugation values were plotted with glucose accumulation over time, a possible relationship among the variables was revealed. The observed peroxidation products could relate low-temperature stress and the resultant low-temperature sweetening to chilling injury and water stress (Wismer *et al.* 1998).

Dormancy

As natural organs or perennation potato tubers can be stored for protracted periods of time. The main factor limiting storage is usually when the dormancy period ends and the tuber sprouts. Mature tubers have a natural dormancy period, which is when the tuber will not sprout whatever the conditions and it lasts for period of weeks or months after the tuber has been harvested. After this natural dormancy is complete the tuber may or may not sprout depending on the conditions in the store. The loss of tuber dormancy and onset of sprout growth is accompanied by numerous biochemical changes, many of which are detrimental to the nutritional and processing qualities of potatoes (Suttle 2004a). Sprouting causes increased weight loss and the conversion of starch into sugar. The elongation of the sprouts can also impede air movement through the potato pile (Kleinkopf *et al.* 2003). The length of the dormancy period and the subsequent sprouting behaviour varies between cultivars and is affected by the previous history of the tubers and the storage conditions. Temperature, light, oxygen concentration, carbon dioxide concentration and the possible presence of volatile substances from the potato affects the length of dormancy period and sprouting (Rastovski and Van Es 1987).

At harvest and for subsequent definite period tubers remain dormant. Dormancy is defined as a period in which there is no visible bud growth and is induced at the beginning of tuberization. Emilsson (1949), Kawakami (1952) and Emilson and Lindblom (1963) all distinguished two states for the tuber buds before sprouting: resting, in which the buds do not grow because of internal factors and dormancy where the buds do not grow because of environmental factors. Goodwin (1966) and Burton (1978) referred to the former state as being dormant. In an earlier study, Burton (1963) referred to

a bud as dormant when it is not growing for any reason. Later, Burton (1982) described the state of endodormancy, when the bud would not grow under favourable environmental conditions, which is because of endogenous factors not resulting from environmental influences. In order to avoid differences in nomenclature, a group of physiologists of the European Association for Potato Research worked on a definition of terms (Reust 1974). They proposed the following: 'Dormancy is the physiological state of the tuber in which autonomous sprout growth will not occur, even when it is placed under ideal conditions for sprouting (darkness, temperature 15–20 °C and about 90% r.h.).'

There is also a lack of agreement among potato physiologists as to the time when measurement of the dormant period should be initiated. Burton (1957, 1989a) was of the opinion that dormancy starts before harvest and suggested that it begins at the time when tubers are initiated. Therefore Burton considered that it was incorrect to measure the dormant period from the date of harvest. Van der Plas (1987) demonstrated the difference in length of the dormancy period between the tuber initiation and harvest time methods. Planting date to sprouting was considered the best practical field measure of dormancy, since it is closely correlated with tuber initiation to sprouting, a method which was more accurate, but difficult to determine (Harris 1992). Not all investigators, however, accept the concept of a true rest and dormant period in the potato tuber and there is divergence of opinion with regard to the definition of terms. Burton (1957) has pointed out the difficulty in recognizing the end of the rest period, since its actual completion may occur some times before the growth of the sprout is noticeable because of the slow rate of cell division. Davidson (1958) concluded that sprout growth was continuous at the apical eye of potato tubers after harvest and there is no incapacity for growth, but this growth is not visible to the naked eye. However, Bruinsma and Swart (1970) stated the buds of the potato tubers were resting during the last weeks before harvest when the tubers are still developing on the mother plant and also for a period immediately after harvest.

According to Davies (1990) light and humidity had no effect on sprout initiation during high-temperature storage of the tubers. However, a slight effect of these two factors may still exist at low storage

temperature. Even after the dormancy period has ended the tuber might not sprout if the conditions, especially temperature, are not conducive. Nakagawa *et al.* (1995) showed that sprouting occurred after about 70 days of storage at 20 °C but did not occur at 4 or 33 °C after 160 days. In experiments described by McSay *et al.* (2003) storage at 3.3, 4.4 and 6.7 °C had similar effects on sprouting and were far less effective than storage at 1.1 and 2.2 °C. In Poland Zarzyńska (2004) showed that weather conditions during growth affected tuber dormancy. The dormancy of tubers harvest in the dry year (2002) was shorter than those of tubers harvested in 1999, 2000 and 2001. Harvest maturity can also have an effect in that fully mature tubers have a shorter dormancy period (Burton 1989a).

Burton (1957) summarized the different theories which have accounted for the cause of dormancy. Probably the first was by Muller Thurgau (1882) who postulated that it was due to a deficiency of soluble carbohydrate. During the dormant period, a gradual production of diastase leads to an increase in sugars, followed by sprouting. Another theory was that it is due to an interruption in O₂ supply caused by suberization of the skin (Appleman 1916). It was limited by the time taken for the diffusion through the skin of sufficient O₂ to complete unspecified processes. Thornton (1939), on the basis of observations of the effects of a low O₂ concentration on sprout growth, produced a theory diametrically opposed to that of Appleman. He suggested the termination of the dormant period by restriction of the O₂ supply because of increased suberization of the periderm in the ageing tuber. Another theory relates to high concentrations of CO₂ in the tuber ends, when this concentration decreases to a low-level dormancy ends (Kidd 1919). The presence of an acid growth-inhibiting substance, which disappears rapidly after harvest (Hemberg 1947, 1949). The latter was criticized by Burton (1956) on the basis of its effect on *Avena coleoptile* (used by Hemberg) is unjustified and that the effects of variety and storage temperature upon growth-promoting, and growth-inhibiting substances in the potato do not, necessarily, bear any relation to the effects of these variable factors on sprouting. The effect of sulphur compounds, and particularly those containing sulphhydryl groups (notably glutathione), in the tuber on cell division (Miller 1931). Accumulation of volatile

substances and their concentration in solution in the cell sap, throughout the life of the potato tuber (Burton 1952).

Dormancy release in tubers by external agents has been an active area of research since the late 19th century (Burton 1957). In addition to solving experimental problems into the control mechanisms associated with dormancy release, external chemical agents possess such practical applications as dormancy breaking of seed tubers for export or local use (Coleman and Coleman 1986). Exogenous applied cytokinins (kinetin or zeatin) are capable of breaking tuber dormancy and simultaneously of reducing the inhibitor complex (Hemberg 1970). On the other hand, Rappaport and Wolf (1969) showed that exogenous GA could terminate dormancy in potatoes. Davies and Ross (1986) suggested, on the basis of histochemical and quantitative analysis of sprouting tubers, that the patterns of starch and protein mobilization could be explained in terms of source-sink relationship between tuber and sprouts. Substances used to date as dormancy-breaking agents have been quite wide ranging in chemistry rindite (a mixture containing ethylene chlorohydrin, ethylene dichloride and carbon tetrachloride in a ratio 7:3:1 v/v/v, respectively) and GA, gasoline, ammonia vapours, O₂ and CO₂. Thornton (1939) suggested that the CO₂ effect was not due to temporary anaerobiosis, since 1–6% CO₂ was most effective in breaking tuber dormancy in the presence of 20–80% O₂ and more effective than complete anaerobiosis caused by storage in an atmosphere of total nitrogen. CO₂ was viewed as an active regulator of tissue metabolism.

Most literature supports the 'inhibitor/promoter' hypothesis with the critical events associated with dormancy release, involving a shift in the growth-regulator ratio in favour of promoters and subsequent establishment of positive feed back between the bud and the mobilized food reserves (Coleman 1987). Hemberg (1965) stated that, with the onset of rapid bud growth at the termination of dormancy, the inhibitor-complex decreases rapidly, although there is no evidence of a specific threshold concentration of abscisic acid (a major component of inhibitor) in the tuber, below which sprouting will occur (Coleman and King 1984). McIntyre and Quick (1984) discussed the importance of water movement within tubers and its possible relationship with sprout growth. They indicated that their

observations support the hypothesis that water movement within tubers and uptake by sprouts may be largely determined by gradients in osmotic potential.

Internal sprouting

Internal sprouting is a malformation in which a lateral sprout grows inward into the tuber. This tuber defect occurs mainly in long-term storage, and then only occasionally. The causes of this disorder appear to be related to low concentrations of CIPC, too late of an application of CIPC or tubers being tightly packed by pile pressure or the presence of excessive dirt and debris that can restrict air circulation. Long-term storage at temperatures above 16 °C that physiologically age the tuber can also contribute to internal sprouting. Ethylene treatment was not associated with internal sprouting (Prange *et al.* 1998). When seed tubers were stored at 2–4 °C for 6 months and then removed to 20 °C and desprouted at 30-day intervals, internal sprouting was observed in some tubers (Ezekiel and Paul 2001).

Temperature

The storage temperature is the most important factor affecting sprouting behaviour. The changes in the balance of growth substances, which may be before the break of bud dormancy has occurred, may be expected to be influenced by temperature (Burton 1989a). In early work Hogetop (1930) investigated the effect of 16 constant temperatures over a range 4.5 to 33 °C and found 24 °C to be the optimal for the loss of dormancy. Wright and Peacock (1934) found that, in general, the higher the storage temperature, over the range of about 4–21 °C, the shorter was the dormancy period after harvest. The work of Schippers (1956) with 41 cultivars at temperatures ranging from 3 to 20 °C showed that, on average, raising the storage temperature from 10 to 20 °C shortened the dormancy period after harvest by 18%. While lowering the temperature from 10 to 5 °C lengthened the period by 67%, and from 10 to 3 °C lengthened it by over 150%. Ophuis (1957) reported that sprouting was retarded with decreasing temperatures below 20 °C and that sprouting could be suppressed for 6–8 months by storage at 4 °C.

Carbon dioxide and oxygen

The influence of CO₂ on changes in respiratory metabolism of whole potatoes may be one of the most

important processes associated with the metabolic effect of CO₂. The changes are especially dependent on the concentration, exposure time, temperature and physiological age of tubers (Harris 1992). Published observations on the effect of CO₂ on the sprouting of potatoes are contradictory. In much of the work CO₂ has been shown to inhibit or retard sprouting. Kardos and Blood (1947) showed a retarding effect on sprout growth when respiratory CO₂ was allowed to accumulate in stores up to 12%. In an atmosphere containing 15% CO₂ Smith (1977) reported that sprout growth in potato could be inhibited at 10 °C. Schmitz (1991) demonstrated some sprout inhibition in an atmosphere containing 8–12% CO₂ in Bintje and Saturna stored at both 6 and 10 °C.

In earlier work Kidd (1919) and Thornton (1939) using O₂ concentrations of 2–6% and 20% CO₂ reported a stimulatory effect of these gas mixtures on sprouting of tubers. Braun (1931) found sprouting to be significantly stimulated at CO₂ levels of only 2.2–9.1%. Burton (1952) also showed that sprouting was increased by passing a gas mixture containing 6.8% CO₂ continuously over the tubers. Later Burton (1958) confirmed the earlier findings that sprout growth was stimulated, at 10 °C, by increasing the concentration of CO₂ in the atmosphere with an optimal concentration of about 2–4% but at this level the concentration in the cell sap would be 0.04–0.05 ml per ml of CO₂. Concentrations above this had a progressively less stimulating effect. Schouten (1992) found that an atmosphere containing either 6% CO₂ with 5% O₂ or 3% CO₂ with 18% O₂ strongly stimulated sprout growth in tubers of the cultivar Agria stored at 6 °C for 3 months.

The effect of O₂ has also been shown by other workers to have both positive and negative effects on sprouting depending on O₂ concentration. In the cultivar Agria sprout growth was strongly inhibited in 0.7% O₂ and stimulated in 1.4 and 2.1% O₂ compared with air (Schouten 1992). According to Rakitin and Suvorov (1935), the growth of potato tuber buds was stimulated by exposure for 1 week to anaerobic conditions. Thornton (1939) found that sprouting could be induced in freshly harvested tubers, for three cultivars, if the concentration of O₂ in the storage atmosphere was reduced to 2%. Burton (1968) also found 2–4% O₂ stimulated the growth of dormant buds. He suggested that these effects of O₂

may be concerned with the optimally anaerobic (and reversible) metabolism of a growth inhibitor. Burton (1973) found that exposure of the tubers to a 1% O₂ concentration for a few days at 10 °C, at the beginning of the storage season, stimulated subsequent sprout growth in air. Workman and Twomey (1969) found that after 10 months of storage in 1% O₂ at 4–5 °C the buds of seed potatoes were still viable. It was reported that sprout growth was strongly inhibited in 1% O₂ at 6 °C but at higher O₂ levels (about 5%), sprout growth was stimulated at both 5 and 10 °C (Lipton 1967, Sherman and Ewing 1983, Schouten 1992).

Hormones

Endogenous hormones appear to play a significant role in tuber dormancy regulation. Both abscissic acid and ethylene are required for dormancy induction, but only abscissic acid is needed to maintain bud dormancy. An increase in cytokinin sensitivity and content appears to be the principal factors leading to the loss of dormancy. Changes in endogenous IAA and GA₃ content do not appear to affect tuber dormancy but they have a role in the regulation of subsequent sprout growth. The levels of ABA increased during tuber formation, remained steady during dormancy and diminished with active bud growth. The first of these processes depends on high levels of GA₃, while interruption of dormancy was determined by an enhanced sensitivity to cytokinins. Once dormancy has been broken, bud growth regulation is related to changes in IAA and GA₃ levels (Suttle 2004a, 2004b).

Cultivar

Burton (1989a) listed many British cultivars and showed wide variation in their natural dormancy period. In India Singh and Ezekiel (2003) measured dormancy period at 18–20 °C for several cultivars and found that for the older ones it was less than 91 days and for newer cultivars it was greater than 126 days. Suttle (2004b) showed that Russet Burbank were still completely dormant after 98 days of storage and dormancy began to end and tubers exhibited limited (<2 mm) sprout growth between 98 and 134 days. In Poland Zarzyńska (2004) also found that cultivars differed in terms of tuber dormancy and that cultivar earliness and dormancy period were not correlated. McSay *et al.* (2003) ranked cultivars from the longest to shortest storage life, using 10% of tubers that had sprouted at 1.1 °C as follows:

- Russet Nugget (112 days);
- Russet Norkotah #3 (109 days);
- Russet Norkotah #8 (95 days);
- Cherry Red (89 days);
- Durango Red (87 days);
- Chipeta (70 days);
- Keystone Russet (<30 days).

Kleinkopf and Olsen (2003) showed an interaction between temperature and cultivar with storage at lower temperature showing the longest time to sprouting (Table 103).

The effect of cultivar on the length of dormancy or resting periods was investigated by Emilsson (1949), Schippers (1956) and Burton (1963). Emilsson (1949) gave values for 51 cultivars stored at 5 °C and divided them into five groups with periods of endodormancy after harvest varying from less than 6 weeks to more than 15 weeks. Schippers (1956) gave a mean duration of dormancy after harvest for 41 cultivars stored at a number of temperatures to be 19.5 weeks. The duration at 10 °C for tubers harvested immature in mid-July ranged from 17 to 27 weeks. Burton (1963) found that the duration of endodormancy for 11 cultivars measured both from the time of tuber initiation and from the time of harvest in the third week of September, was 20–33 weeks and 5–14 weeks, respectively, at 10 °C. In a study of the cultivar Russet Burbank by Campbell *et al.* (1996) the tubers were completely dormant at the time of harvest but those removed to 20 °C after 120 days of storage at 3 °C had about 50% sprouting while those removed after 223 days had 100% sprouting. They suggested that during endodormancy cell division in the tuber meristems was regulated indirectly by post-transcriptional regulation of genes controlling the cell cycle (Campbell *et al.* 1996). Suttle (1995) found that Russet Burbank tubers stored at 20 °C dormancy was broken and

sprout growth began after 35–50 days while at 3 °C dormancy was broken after 50–80 days but subsequent sprout growth was initiated only after transfer to 20 °C. It was also shown that after 35 days at 3 °C endogenous levels of free ABA were highest, intermediate in tubers transferred from 3 to 20 °C 7 days prior to analysis and lowest in tubers stored at 20 °C. Regardless of temperature, free ABA levels declined with increasing duration of storage. The onset of sprouting was not associated with any threshold level of free ABA. It was suggested that a decline in endogenous ABA below a threshold level was not a prerequisite for the loss of tuber dormancy and the onset of sprout growth (Suttle 1995). Thomson *et al.* (1987) succeeded in breeding for long dormancy. They crossed clones from *Solanum burthaultii* with commercial cultivars and produced tubers with dormancy considerably longer than control cultivars (Harris 1992).

Dormancy and sprouting

As indicated above potato tubers have natural dormancy before they begin to sprout, which is affected by storage temperature and varies with cultivars (Table 103).

Control of sprouting

The limiting factor in storage is usually when the dormancy period ends and the tuber regrows. The length of the dormancy period and sprouting behaviour depend on the cultivar, the previous history of the tubers and the storage conditions. Even after the dormancy period has ended the tuber might not sprout if the conditions, especially temperature, are not conducive. Sprouting is normally suppressed at 5 °C and below. In Poland Zarzyńska (2004) showed that weather conditions during growth affected tuber dormancy. The dormancy of tubers harvest in the dry year (2002) was shorter than those of tubers harvested in 1999, 2000 and 2001 that had higher precipitation.

Control of tuber dormancy is also confounded with tuber quality particularly their sugar content. Storage at 5 °C is associated with conversion of starch into sugar that is not acceptable where the tubers are to be processed, but again this is related to cultivar. For example Hebeisen *et al.* (2007) reported that Désirée tubers contained four times more reducing sugars than Victoria tubers. The higher sugar content

Table 103 The approximate number of days until dormancy was broken for six russet potato cultivars at three storage temperatures (source: adapted from Kleinkopf and Olsen 2003)

Cultivar (°C)	5.6	7.2	8.9
Russet Burbank	150	135	120
Ranger Russet	75	60	50
Gem Russet	135	115	90
Summit Russet	150	125	100
Umatilla Russet	140	120	80
Bannock Russet	135	110	80

may also be unacceptable for tubers that are sold fresh. They reported that since October 2004 Swiss retailers have offered ware potatoes stored at higher temperatures.

CIPC

Sprouting can be suppressed to extend the storage life by applying growth-regulating chemicals to the crop (Burton 1989a). The most commonly used is CIPC (3-chloro-isopropyl-*N*-phenyl carbamate), also called chloropropham. CIPC is a herbicide and plant growth regulator. Sprout suppressant chemicals are applied to crops to maintain commercial acceptability when low-temperature storage is not a suitable option. There are several chemicals that are used to prevent sprouting but CIPC is used throughout the world and accounted for 80% of the chemical applied to stored ware potatoes in the United Kingdom (Fox *et al.* 2000). Hebeisen *et al.* (2007) reported that in Switzerland, ware potatoes were generally stored long term at 4–5 °C and all cultivars they tested stored at 4 °C contained about 5 g kg⁻¹ f.w. of reducing sugars, whereas the sugar content of tubers stored at 7 °C varied from 1 g kg⁻¹ f.w. for those where CIPC was applied to 1.4 g kg⁻¹ f.w. where no CIPC was applied.

CIPC is formulated with a solvent and is applied with equipment originally designed for insecticide fogging that is called swingfog or pulsfog. The equipment heats the formulation to about 200 °C when it forms into a vapour, which is then distributed over the tubers through the internal forced ventilation and air distribution system (Noël *et al.* 2004). Application of CIPC during storage requires good air circulation to ensure that all tubers are treated. Afek and Warshavsky (1998) described a system with three fans (1 m in diameter) that forced the combination of humidified air and CIPC into the bottom of the plenum. This mist reached the perforated ducts and was then pulled up through the potato pile to the vacuum space produced above the pile. The first treatment should be carried out after the crop has been cured. Delayed application may cause formation of internal sprouts in the tuber. It is usually applied repeatedly, as and when required with the first application before sprout growth starts and subsequently repeated up to three or four times depending on the length of storage, the storage temperature and the cultivar.

McGowan *et al.* (2006) reported that thermal fogging of CIPC has been associated with a transient, but not fully reversible, darkening in fry colour of potato crisps or chips. The by-products of combustion used to generate the CIPC vapour have been associated with these effects. These by-products include heat, CO₂ and ethylene. Ethylene produced by thermal fogging caused a darkening of fry colour for at least 28 days after application. The extent of deterioration in processing quality was shown to depend on the concentration of ethylene and exposure time of the crop. Ethylene can also affect the action of CIPC in preventing sprouting (Abeles *et al.* 1992, Suttle 1996, Saltveit 2002, Dowd 2004). Deterioration in processing quality was often followed by some recovery in fry colour, though this was usually incomplete. This problem was addressed by designing an applicator specifically for CIPC aerosol application. Also a catalytic conversion system was developed that resulted in a headspace yield of ethylene below 0.2 µl L⁻¹ following CIPC applications. Such applications resulted in an improvement in processing quality compared with standard treatments. Another alternative is to apply the CIPC as the crop is being loaded into the store. This could avoid the use of thermal fogging machines at the start of storage and therefore the detrimental effect of ethylene generated by these machines. This method of application has been associated with better distribution than thermal fog treatment because it is applied per box as opposed to per store. A granular formulation is available for application to tubers as they are loaded into store. However, application at this time can impede the curing process and result in increased levels of deep skin spot infections. Standard commercial practice is to apply CIPC at 60 g tonne⁻¹ of cured potatoes (Afek and Warshavsky 1998). Another alternative is treating the tubers with 1-MCP. Prange *et al.* (2005) concluded that 1 µl L⁻¹ 1-MCP for 48 h at 9 °C could be used to control fry colour darkening induced by ethylene (4 µl L⁻¹) without affecting ethylene control of tuber sprouting. They proposed that crops can regain sensitivity to ethylene by producing new ethylene receptors. However, they found that the number of 1-MCP applications required varied between the two cultivars they tested in that one application was sufficient in Russet Burbank but not in Shepody which started darkening 4 weeks after exposure in the single ethylene + 1-MCP treatment.

The application of sprout suppressants to potatoes is governed by law where there is a maximum residue level of all sprout suppressants permitted in tubers on sale to the public. These are calculated on the basis of the amount that will effectively control sprouting while ensuring that the consumers are protected against excessive quantities of added chemicals in the food they eat. MRL for CIPC from the requirements of the Food Quality Protection Act of 1996 resulted in a reduction in allowable CIPC residue on fresh potatoes in the United States from 50 to 30 mg kg⁻¹. This mandate coincided with tolerance reductions or restrictions for use of CIPC in other parts of the world (Kleinkopf *et al.* 2003). Noël *et al.* (2004) gave the CIPC maximum residue limit as 5 mg kg⁻¹ in Belgium on potatoes which have been neither brushed nor washed. Studies carried out in 1999 in Belgium showed that 36% of potato samples contained CIPC residues and that 7.9% of them exceeded the 5 mg kg⁻¹ MRL. The heterogeneity of sprout inhibitor application would be the one of the causes of over dosage. However, this heterogeneity would also cause under dosages leading to problems when controlling the sprouting in potatoes stored at over 6 °C. An almost systematic over-dosage of the CIPC quantity was observed. However, out of the 35 samples analysed, only two had residue contents higher than the MRL. The tests carried out showed that mechanical dusting, even though having a less constant flow rate than sprayers, led to less important variation of the residue between samples (Noël *et al.* 2002).

CIPC used as a sprout suppressant on stored potatoes, received European Annex I clearance under Directive EC/91/414 and, as part of that process, a MRL of 10 mg kg⁻¹ was set, which came into force in April 2007. In addition to the EU review, studies have been evaluated by the United States and many European countries prior to the registration of CIPC. The product has recently been reviewed by the WHO (World Health Organisation), JMPR (Joint Meeting on Pesticide Residues) and the US EPA (Environmental Protection Agency). Where the reviews are complete, it has been concluded that CIPC does not pose a risk to the health of workers and consumers of treated potatoes. The JMPR proposed an MRL of 30 µg L⁻¹ for fresh potatoes while the EU review is considering an MRL of 10 µg L⁻¹. Processing considerably reduces the CIPC residue and this has been

confirmed in analysis of marketed produce where washing, peeling and cooking reduced the levels of residue to 1% of its already marginal post-storage, treated condition. The UK Advisory Committee on Pesticides made a series of recommendations. These were that the total amount of chlorpropham applied to potatoes destined for the fresh market must not exceed 36 g chlorpropham tonne⁻¹. Where the total dose exceeded 36 g CIPC tonne⁻¹ then the crop must only be used for commercial processing. The maximum amount of CIPC applied to processing potatoes must not exceed 63.75 g CIPC tonne⁻¹. These limits took immediate effect and refer to the total amount of CIPC applied, not individual products. The MRL for CIPC from the Environmental Protection Agency in the United States were revised in 1996 to 30 mg kg⁻¹ (Kleinkopf *et al.* 1997). Lentza-Rizos and Balokas (2001) found that the concentrations of CIPC in individual potato tubers ranged between:

- 1.8 and 7.6 mg kg⁻¹ 10 days post-application (mean 3.8 mg kg⁻¹);
- 0.7 and 4.0 mg kg⁻¹ 28 days post-application (mean 2.9 mg kg⁻¹);
- 0.8 and 3.8 mg kg⁻¹ 65 days post-application (mean 2.2 mg kg⁻¹);

and in composite samples ranged between:

- 4.3 and 6.1 mg kg⁻¹ 10 days post-application (mean 4.9 mg kg⁻¹);
- 3.1 and 4.2 mg kg⁻¹ 28 days post-application (mean 3.8 mg kg⁻¹);
- 2.6 and 3.2 mg kg⁻¹ 65 days post-application (mean 2.9 mg kg⁻¹).

Peeling removed 91–98% of the total residue and washing reduced residues by 33–47%. Detectable residues were found in boiled potatoes and the boiling water, also in French fries (chips) and the frying oil (Lentza-Rizos and Balokas 2001).

Residue concentrations of commercially treated CIPC in the cultivar Russet Burbank were evaluated after thermal aerosol treatment at maximum labelled rates by Kleinkopf *et al.* (1997). The aerosol was applied after the potatoes had been placed in store and curing was complete. Average residue concentrations 4 days after the initial application ranged from 6 to 8 mg kg⁻¹ f.w. depending on the storage temperature and the application rates. A second aerosol treatment applied 90 days after the first treatment kept

the residue concentrations above 5 mg kg^{-1} for the duration of the storage period. A direct spray application to the tubers at various times during the study raised the average CIPC concentration an additional $2\text{--}3 \text{ mg kg}^{-1}$.

Residue concentrations of CIPC were greater on tubers near the bottom of the pile 8 mg kg^{-1} than near the top of the pile 3 mg kg^{-1} . It was concluded that these variations are appropriate justification for the development of improved application methodology (Kleinkopf *et al.* 1997). Burfoot *et al.* (1996) developed a numerical model was developed to predict the distribution of deposits of CIPC in box potato stores. The model considered the movements of the CIPC by forced convection, sedimentation, natural convection and diffusion. Measurements have mostly shown high levels of CIPC on the top of the uppermost box, with levels decreasing towards the floor of the store. The model predicted this pattern and indicated that particle size, the temperature difference between the air inside and around the boxes and the application rate of the chemical have a large effect on the levels and uniformity of CIPC deposits. Smaller particles ($2 \mu\text{m}$) can lead to better uniformity of distribution, but they are prone to natural convection effects which are difficult to control and they are slow to deposit which could lead to greater losses from the store. Lewis *et al.* (1996) found that the residues of thiabendazole, tecnazene (TCNB) and chlorpropham at commercial potato stores were significantly reduced to less than 2% for potato crisps and less than 10% for jacket potato crisps of the maximum theoretical residue carry through level. Putz (1986) discussed the use of IPC, CIPC, tecnazene, MH and dimethylnaphthalene as sprouting inhibitors in relation to residue levels. Concentrations of IPC and CIPC in potatoes were well below tolerance thresholds. Most of the residues were found on the peel; potato processing markedly reduced residue concentration. Tecnazene is a fungicide as well as a potato sprout suppressant but due to insufficient data to perform an adequate risk assessment, use of all pesticides containing tecnazene was revoked in January 2000 in the United Kingdom.

Tubers of the cultivar Primura were treated with IPC and/or CIPC applied as a powder or aerosol and residues were determined after 15 and 30 days of storage in both peeled and not peeled tubers by Conte *et al.* (1995). In the powder treatment containing IPC

and CIPC, only residues of IPC were found. In the aerosol treatment containing only CIPC, both CIPC and IPC were found. Peeling potatoes resulted in large decreases in sprout inhibitor levels in the aerosol treatment.

Potatoes are exported by sea freight throughout the world and sprouting can occur during transport. Simulated sea-freight trials at 25°C and 85% r.h. for 5 weeks showed $25 \text{ g CIPC tonne}^{-1}$ of tubers applied as a spray gave near complete control of sprouting. A CIPC rate of 50 g tonne^{-1} applied as a spray resulted in an MRL of 50 mg kg^{-1} . Although in the experiments lower rates were highly effective, the optimal rate needed to be confirmed under actual sea-freight conditions. The difference in performance between CIPC applied as a fog or spray is likely to be related to differences in rate of application ($20 \text{ g a.i. tonne}^{-1}$ compared to $50 \text{ g a.i. tonne}^{-1}$). Also almost all CIPC spray will go directly on to the tubers, whereas some CIPC fog will settle on the tent used for fogging or the jute bags holding the potatoes (Brash 1996).

Ethylene

Ethylene has been shown to both break dormancy and suppress breaking of dormancy of tubers depending on the concentration and exposure time (Burton 1989a). Foukaraki *et al.* (2012b) reported that an ethylene concentration of $50 \mu\text{L}^{-1}$ has been approved by the Chemicals Regulation Directorate in the United Kingdom for use in potato storage, but a continuous treatment of $10 \mu\text{L}^{-1}$ was more commonly used commercially. In some early work when potatoes and apples were stored together, the sprouting of the potatoes was shown to be suppressed (Huelin 1933). The effect was related to the ethylene given out by the ripening apples. Rylski *et al.* (1974) found that potatoes exposed to ethylene in storage had a shorter rest period before sprouting. This was confirmed by Wills *et al.* (2003) who stored the cultivar Sebago at 20°C in different ethylene concentrations. They found that the average time taken for one sprout to develop on a tuber was 32 days in less than $0.005 \mu\text{L}^{-1}$, 23.7 days in $0.1 \mu\text{L}^{-1}$ and 22.3 days in $10 \mu\text{L}^{-1}$ ethylene.

Ethylene may have an indirect effect on dormancy by stimulating the production of other growth regulators such as gibberellins (Thomas 1981). In more recent work both in laboratory studies and a

commercial store the ethylene applied continuously in the laboratory at $166 \mu\text{mol m}^{-3}$ delayed the appearance of sprouts on Russet Burbank for 5–15 weeks compared with untreated tubers (Prange *et al.* 1998). In the ethylene-treated tubers in both laboratory and commercial storage studies, sprouts appeared on many eyes, but most of them remained very small (<5 mm long). Sprouts longer than 5 mm appeared after 15 weeks but did not exceed 12 mm in the laboratory and 59 mm in the commercial stores. Sprouts on ethylene-treated tubers were more easily detached up to 6 weeks after ethylene treatment ended compared with non-treated tubers. In both studies ethylene treatment was not associated with decay, disorder or internal sprouting problems. Continuous exposure to ethylene was an effective sprout control agent, but it produced a darker fry colour compared with CIPC-treated potatoes.

Ethylene has also been shown to affect the quality of stored tubers. Storage of the cultivars Norgold and Russet Burbank at 3°C in air led to accumulation of sugars and a decline in fry colour to unacceptable levels within 2 weeks. Storage in $100 \mu\text{L L}^{-1}$ ethylene in air and low O_2 at 3°C delayed decline in colour by 6–8 weeks compared with storage in air. Storage in $1000 \mu\text{L L}^{-1}$ ethylene apparently reduced rate of conversion of sucrose into hexose sugars. The low O_2 atmosphere reduced the extent of sucrose accumulation and rate of conversion of sucrose into hexose sugars during storage (Parkin and Schwobe 1990). In storage experiments on Russet Burbank over three seasons at 9°C for 25 weeks Daniels-Lake *et al.* (2012) reported that 400, 40 and $4 \mu\text{L L}^{-1}$ ethylene inhibited sprout growth as effectively as CIPC, while for tubers treated with $0.4 \mu\text{L L}^{-1}$ ethylene sprouting was midway between CIPC and the untreated control. However, they also found that fry colour of tubers from 40 to $4 \mu\text{L L}^{-1}$ ethylene treatments was still darker than tubers stored with CIPC. Ethylene was delivered in the ventilation airstream at about 0.5 air exchanges per hour for 6 h each day. These results would be consistent with the effects of ethylene exposure increasing tuber sugar content. Storing potatoes at 6°C in the presence of $10 \mu\text{L L}^{-1}$ ethylene was reported by Foukaraki *et al.* (2009) to increase in the sugar content of the five cultivar they tested. These were Sylvana, Marfona, Estima, Desiree and Fianna. However, they found that the different cultivars responded differently and concluded that it may be possible to use

ethylene on Estima and Desiree without significantly affecting their quality upon processing since they were least affected by ethylene. In a comparison of two cultivars stored at 6°C for 6 months Foukaraki *et al.* (2012b) reported that ethylene applied after the dormancy break reduced sprouting of Sylvana but not Marfona, but tubers exposed to ethylene of both cultivars contained higher sucrose, glucose and fructose concentrations than those not exposed. Tubers of the cultivar Marfona were exposed to about $1 \mu\text{L L}^{-1}$ 1-MCP for 24 h and then stored at 6°C in the presence or absence of continuous ethylene at $10 \mu\text{L L}^{-1}$ at 6°C for 30 weeks by Foukaraki *et al.* (2012a). 1-MCP exposure before storage did not affect the total sprout number of tubers, but the action of ethylene was significantly suppressed in terms of sugar accumulation of tubers. The tubers that were exposed to ethylene that had not been previously exposed to 1-MCP had significantly higher sucrose, glucose and fructose content than those that been exposed 1-MCP.

Maleic hydrazide

Swietlińska and Zuk (1978) reported that MH acts as an inhibitor for the synthesis of nucleic acids and proteins and Burton (1989a) reported that MH also reduced cell division as well as prevented the synthesis of proteins, RNA and DNA. MH is applied to potatoes as a foliar application in the field 2–6 weeks before harvest or before the haulm is killed or removed. It is essential that it is applied by spraying the plants well before harvest so that a residue is translocated from the leaves and stems to the tubers. The timing of application is crucial because if it is too early, the yield will be reduced, but late application may not allow sufficient time for the MH to be translocated in sufficient quantities to the tubers (Van Es and Hartmans 1987, Yada *et al.* 1991). Burton (1989a) reported that MH was detected in tubers 3–4 days after application but 10–15 days were required for sufficient quantities to be translocated to inhibit sprouting. Commercially the diethanolamine or sodium salt were used at the rate of 2.5 kg ha^{-1} delivered as a high volume spray of $1000\text{--}1500 \text{ L ha}^{-1}$.

Propham

IPC (isopropyl-*N*-phenyl carbamate) has also been used either by itself or in a formulation with CIPC. Wessel and Wustman (1990) applied a mixture of

IPC and CIPC at 11 mg kg⁻¹ a.i. to the cultivar Bintje and stored them for 4 months at 6, 10 or 25 °C. The applications were repeated at 80% sprouting in those stored at 10 and 25 °C. Treatments controlled sprouting and powder and liquid formulations were equally effective. The residue levels of all treatments, 4 weeks after application, were less than 2 mg kg⁻¹ in washed unpeeled tubers. Conte *et al.* (1995) determined residues after 15 and 30 days of storage in peeled and unpeeled tubers that had been treated with mixture of IPC and CIPC. The treatment prevented sprouting for more than 3 months. In the powder formulation only residues of IPC were found. Peeling tubers resulted in large decreases in sprout inhibitor levels.

TCNB

TCNB (2,3,5,6-tetrachloronitrobenzene), also called tecnazene, was originally marketed as a fungicide (Fuserex); therefore it had the effect of both controlling some postharvest diseases and controlling sprouting. Burton (1989a) reported that TCNB should be applied at the rate of 100 g tonne⁻¹ of tubers. It was first applied in an inert filler (koalin or kieselguhr) dusting it onto the tubers as they were loaded into the store usually with a dusting device mounted on the elevator. Van Es and Hartmans (1987) reported that it was not effective in controlling sprouting if dormancy is broken, if the store is excessively ventilated or if the storage temperature is kept above 10 °C.

Irradiation

Leszczynski *et al.* (1992) showed that irradiation inhibited sprouting throughout 6 months of subsequent storage at 4, 7 or 13 °C. Irradiation of at least 35 Gy can be used to suppress sprouting in potatoes (Burton and Hannan 1957, Ranganna *et al.* 1997). Sparrow and Christensen (1954) showed that irradiated tubers did not sprout during 15 months of storage at 4.4 °C. A dosage rate of 100 Gy was found to be adequate, but lower rates of about 35 Gy can be used to delay sprouting without the side effects that were observed on tubers exposed to higher doses (Burton and Hannan 1957). Dallyn and Sawyer (1959, quoted by Salunkhe *et al.* 1991) demonstrated interactions between temperature and dosage of irradiation. They also showed that a dose of 100 Gy was effective in preventing sprouting of potatoes in storage for 6 months

at 10 and 21.1 °C, but 50 Gy was equally effective when the tubers were stored at 4.4 °C.

Irradiation can affect tuber quality. Russet Burbank tubers were irradiated with 0, 50, 100 or 200 Gy of γ -rays and then stored for 3 months at 10 or 15.5 °C. Irradiation suppressed sprouting but also decreased reducing and non-reducing sugar contents after storage. Irradiation at 200 Gy decreased reducing sugars from 1.7 to 0.9%. Irradiation at 100 Gy dosage caused the least changes resulting in only a 5% decrease in non-reducing sugar content (Badshah *et al.* 1990).

The cultivars Desiree and Metal tubers were irradiated with 0, 50, 100 and 500 Gy γ -rays and stored at 5 or 20–25 °C for 6 months. The control samples of Desiree showed higher respiration rates than the irradiated tubers (Alwakdi *et al.* 1991). The cultivars Janka, San and Bobr tubers were exposed to 150 Gy γ -radiation and together with untreated tubers were stored for 6 months at 4, 7 or 13 °C and 85–90% r.h. Irradiated tubers were lower in starch content but higher in sugar content, especially sucrose. Irradiation also increased susceptibility to enzymic browning but fry colour of the chips did not depend on irradiation but on storage temperature. The highest dry matter losses occurred in non-irradiated tubers stored at 13 °C for 6 months and the highest starch losses in irradiated tubers stored at 4 °C (Leszczynski *et al.* 1992). Although the law may permit this there is consumer resistance and economic factors against the use of irradiation and it is rarely applied commercially.

Controlled atmosphere storage

The amount of O₂ and CO₂ in the atmosphere of a potato store can affect the sprouting, rotting, physiological disorders, respiration rate, sugar content and processing quality of tubers. As early as 1918 (Anonymous 1919) work being carried out at the Low Temperature Research Station in Cambridge described 'Interesting results in stopping sprouting of potatoes have been obtained ... proving the importance of the composition of the air'. Kidd (1919) was also working on the effects of CO₂ and O₂ on sprouting of potatoes. Kubo *et al.* (1989a) claimed that exposure of tubers to high CO₂ produced little or no effect on sprouting. In contrast Hartmans *et al.* (1990) found that sprouting was inhibited in 3% CO₂ or higher, but at 7% CO₂ partial deterioration occurred and there was an increase in sugar content.

Khanbari and Thompson (2004) found that there was almost complete sprout inhibition, low weight loss and maintenance of a healthy skin for all the cultivars they tested stored in 9.4% CO₂ with 3.6% O₂ at 5 °C for 25 weeks (Table 104). When tubers from this treatment were stored for further 20 weeks in air at 5 °C the skin remained healthy and they did not sprout while the tubers which had been previously stored in air or other controlled atmosphere combinations sprouted quickly. This residual effect of controlled atmosphere storage could have major implications in that it presents an opportunity to replace chemical treatments in controlling sprouting in stored potatoes. Schouten (1992) found that some inhibition of sprout growth occurred in 6% CO₂ and sprouting was strongly inhibited in 1% O₂ at 6 °C. However he found that pathological breakdown may develop at this O₂ level and concluded that controlled atmosphere storage at 6 °C was not an alternative to chemical control of sprout growth for ware tubers. In the early phase of storage Schouten (1994) showed that sprouting was stimulated in 3–6% CO₂ and inhibited in 9% CO₂. During the later

phase all CO₂ concentrations inhibited sprouting, but reconditioning after storage stimulated sprouting (Schouten 1994). Lipton (1967) found that in storage 15 or 20 °C black heart developed in tubers held in 0.5 or 1% O₂.

Hot water treatment

A study was conducted by Ranganna *et al.* (1998) to determine whether sprouting of tubers during storage can be controlled by a single pre-storage thermal treatment without affecting quality. The study demonstrated that Superior tubers can be stored for 12 weeks at either 8 or 18 °C without sprouting, if they had been submerged in a hot water bath at 57.5 °C for 20–30 min with no evidence of damage due to the thermal treatment.

Ozone

O₃ is a powerful oxidizing agent and was tested on Russet Burbank tubers as a potential sprout suppressant on by Daniels-Lake *et al.* (1996). They found that O₃ was a less effective sprout suppressant than CIPC and that there were no differences in sucrose,

Table 104 Sugars (g 100 g⁻¹ dry weight) in tubers of three potato cultivars stored for 25 weeks under different CA at 5 and 10 °C and reconditioned for 2 weeks at 20 °C (source: adapted from Khanbari and Thompson 1996)

Cultivars	Gas combinations % CO ₂ , % O ₂	5 °C			10 °C		
		Sucrose	RS ^a	TS ^b	Sucrose	RS	TS
Record	9.4, 3.6	0.757	0.216	0.973	0.910	0.490	1.400
	6.4, 3.6	0.761	0.348	1.109	1.385	1.138	2.523
	3.6, 3.6	0.622	0.534	1.156	1.600	0.749	2.349
	0.4, 3.6	0.789	0.510	1.299	0.652	0.523	1.175
	0.5, 21.0	0.323	0.730	1.053	0.998	0.634	1.632
	Mean	0.650	0.488	1.138	1.109	0.707	1.816
Saturna	9.4, 3.6	0.897	0.324	1.221	0.685	0.233	0.918
	6.4, 3.6	0.327	0.612	0.993	0.643	0.240	0.883
	3.6, 3.6	0.440	0.382	0.822	0.725	0.358	1.083
	0.4, 3.6	0.291	0.220	0.511	0.803	0.117	0.920
	0.5, 21.0	0.216	0.615	0.831	0.789	0.405	1.194
	Mean	0.434	0.473	0.907	0.729	0.271	1.000
Hermes	9.4, 3.7	0.371	0.480	0.851	0.256	0.219	0.475
	6.4, 3.7	0.215	0.332	0.547	1.364	0.472	1.836
	3.6, 3.5	0.494	0.735	1.229	0.882	0.267	1.149
	0.4, 3.6	0.287	0.428	0.715	0.585	0.303	0.888
	0.5, 21.0	0.695	0.932	1.627	0.617	0.510	1.127
	Mean	0.412	0.682	1.094	0.741	0.354	1.095

^aReducing sugars.

^bTotal sugars.

reducing sugars or fry colour between tubers stored in air, O₃ or CIPC.

NAA

Daines and Campbell (1946) reported that α -naphthalene acetic acid methyl ester successfully inhibited sprouting on the cultivars Katahdin and Cobbler, but some injury was reported. They found that it was more effective when applied as a dust than when it was distributed on paper strips.

Hydrogen peroxide

Afek *et al.* (2005) showed that Desiree treated with four applications of 'hydrogen peroxide plus' or CIPC had no sprouting while those not treated had 84% sprouting after 6 months of storage at $10 \pm 1^\circ\text{C}$. However, a single treatment with hydrogen peroxide plus or CIPC resulted in 61 and 58%, respectively, sprouting compared to 87% in those not treated control. The application of H₂O₂ to organic produce is allowed by the National Organic Program standards in the United States. However, some H₂O₂ products contain adjuvants that are not allowed on organic produce. These products are labelled for application through the humidification system in potato storage.

Other chemicals

Nonanol (3-5-5-trimethyl hexanol), dipropargyl ether, dipropargyl alcohol, iso-propylphenyl carbamate, 3-chloro-iso-propylphenyl carbamate, 2,3,5,6-tetrachloronitrobenzene, 2,4,5-trichloronitrobenzene, 2,4,6-trichloronitrobenzene, 3,4,5-trichloronitrobenzene, ethyl ester of 2,4,5-trichlorophenoxy acetic acid, methylnaphthylmethyl ether and many other chemicals have been shown to have an effect on tuber sprouting. None of these are used commercially indeed some have been specifically banned on food (Burton 1989a). Other chemicals that have been tested as sprout suppressants in potatoes include ABA, IAA, camptothecin, volatile monoterpenes, jasmonates, ethanol, dichlorobenil dimethylnaphthalene and di-isopropylnaphthalene. It seems unlikely that any of them have ever been used commercially or, if they have, only for a short period.

Curing

The first work to be published on curing was by Priestley and Woffenden (1923) and subsequently by Artschwager (1927) who described the process

in detail. Curing is carried out as soon as possible after harvest to heal any damaged areas on the tuber surface to reduce the chance of micro-organism infection and reduce weight loss and desiccation. It involves suberin being deposited in the parenchymatous cells just below the damaged area of the tuber. *Suberin* refers to a polymer-containing phenolics and long chain decarboxylic, hydroxy and perhaps epoxy fatty acids, which provides initial protection to the tuber by forming a highly lipophilic coating within and on the surface of tissues. Burton (1989a) suggested that its early response is probably due to enzymes induced or stimulated by an endogenous growth regulator. There are some indications that the fatty acids may also act as phytoalexins and the peroxides and epoxides may have toxic effects on infectious agents (Galliard 1975). Subsequently, below the suberized cells, a meristematic layer of cells is formed which is the periderm and is also called the cork cambium. This produces new cells that contain lignin, which seal off the damaged area. Both these processes are temperature and humidity sensitive (Burton 1989a, Wigginton 1974).

The time required for suberization to begin was shown to be 1 day at 21°C and above, 2 days at 15°C , 3 days at 10°C , 5–8 days at 5°C and greater than 8 days at 2.5°C . The time for the formation of periderm after suberization depends on cultivar but in general it takes about 1 day at 15°C and over, 3 days at 10°C and 5 days at 7°C . No periderm formation occurred within 10 days at 5°C (Burton 1989a, Wigginton 1974). Anonymous (1985) stated that the curing process ceased at 4°C and therefore expressed the curing requirement in day degrees above 5°C . This means that for 6°C theoretically it would require 150 days to complete suberization and periderm formation, that is 150 divided by 1 or at 21°C it would be 150 divided by $(21 - 5) =$ about 9½ days (Table 105).

Another important factor that controls curing is the environmental humidity around the potato tuber. At 12°C and a vapour pressure deficit (VPD) of 3.8 mm Hg, that is about 60% r.h., there was no suberin or periderm formed within 6 days. At the same temperature and 2.7 mm Hg VPD (80% r.h.) 1–1.5 layers of suberized cells had formed, and at 0.6 mm Hg VPD (94% r.h.) there were two layers of well suberized cells. At the two higher VPD no periderm was formed, but at the lower VPD a periderm was formed within

Table 105 The effects of temperature on speed of curing of potatoes (source: adapted from Burton 1969)

Curing temperature (°C)	Approximate curing time (days)
10	30
11	25
12	21 ¹ / ₂
13	18 ³ / ₄
14	16 ¹ / ₂
15	15
16	13 ¹ / ₂
17	12 ¹ / ₂
18	11 ¹ / ₂
19	10 ³ / ₄
20	10
21	9 ¹ / ₂

9 days. In another experiment which compared 2.2 mm Hg (68% r.h.) with 0.4 mm Hg VPD at 6.5 °C (94% r.h.) during 53 days of storage, suberization had occurred at both VPD but periderm did not occur at the higher but was well developed at the lower VPD (Burton 1989a). Most chemical sprout suppressants inhibit periderm formation. Kim *et al.* (1993) showed that in storage of 90% r.h. a good periderm layer was formed in 6 days at 18 °C, in 10 days at 15 °C and in 12 days at 13 °C. Most chemical sprout suppressants inhibit periderm formation and levels of CO₂ can inhibit curing (Butchbaker *et al.* 1967). Lulai and Suttle (2004) found that treatment with AVG inhibited wound-induced ethylene production by about 90% but did not affect wound-induced suberization. They also found that although increased ethylene evolution was part of the tuber wound response, ethylene was not required for wound-induced suberization of the existing cells at the wound surface during the first 2–4 days of wound-healing or subsequent suberization of phellem cells (between 4 and 9 days) created by the wound-induced formation of the phellogen.

Storage temperature

Sprouting is among the most important limiting factors in storage and storage temperature is accepted to be the most important factor affecting sprouting behaviour. The changes in the balance of growth substances, which may be before the break of bud dormancy can occur, may be expected to be influenced by temperature (Burton 1989a). Hogetop (1930) investigated the effect of 16 constant

temperatures over a range 4.5–33 °C and found 24 °C to be the optimal for the loss of dormancy. Wright and Peacock (1934) found that, in general, the higher the storage temperature, over the range of about 4–21 °C, the shorter was the dormancy period after harvest. The extensive work of Schippers (1956) with 41 cultivars at temperatures ranging from 3 to 20 °C showed that, on average, raising the storage temperature from 10 to 20 °C shortened the dormancy period after harvest by 18%. While lowering the temperature from 10 to 5 °C lengthened the period by 67% and from 10 to 3 °C lengthened it by over 150%. Ophuis (1957) reported that sprouting was retarded with decreasing temperatures below 20 °C and that sprouting could be suppressed for 6–8 months by storage at 4 °C. Wurr and Allen (1976) found that a storage period of 14 days at 2–3 °C, followed by storage at 15.6 °C, was favourable for sprouting. The sprouts developed earlier and sprout length was increased. Allen *et al.* (1978) described this effect for a number of cultivars including Desiree. In other cultivars, however, this low-temperature treatment increased the number of sprouts developing per tuber. Seed tubers of the cultivars Atlantic, Dejima, Jopung and Superior were stored at 4, 8 and 12 °C in Pyoungchang in Korea. Dejima had the highest sprouting and growth rates. Storage at 8 °C produced the highest number of sprouts per tuber, whereas the highest sprout dry weight per tuber was produced at 12 °C. Sprout dry matter content was the highest at 4 °C (Park and Son 1997).

To optimize the storage life of potatoes, close control of temperature is essential. Metabolic reactions which occur in living material are affected by temperature and over a range of temperatures tolerated by living organisms will generally increase exponentially with increasing temperature. This relationship was described by Van't Hoff who showed that for every 10 °C rise in temperature the rate of a chemical reaction will approximately double. This is called the temperature quotient (*Q*₁₀) which can be described by the following:

$$Q_{10} = \frac{10(t_2 - t_1)}{(R_2/R_1)}$$

where:

R = respiration rate,
t = temperature.

However, this equation was corrected by B.C. Stenning (quoted by Thompson 1996) as:

$$Q_{10} = \frac{(10/t_2 - t_1)}{(R_2/R_1)}.$$

Burton (1982) showed that the relationship was not quite so simple as it applies to single chemical reactions while in plant tissue there are many interacting processes taking place. Phan (1987) pointed out that within the range of 1 and 40 °C the Arrhenius plot is relevant and the increase in speed of most reactions is 2.3 for every 10 °C rise in temperature:

$$Q_{10} = (Vt + 10)/Vt \sim 2.3$$

where:

V = velocity of the reaction,
 t = absolute temperature.

The relationship between temperature and respiration rates of crops has been reviewed by Hardenburg *et al.* (1990). Burton (1968) showed that for potatoes the relationship between temperature and respiration is not linear and the respiration rate actually increased at lower temperatures (Figure 49). Respiration rates of tubers stored at 4 or 20 °C were low; at 33 °C respiration rate was initially high, but decreased during storage Nakagawa *et al.* (1995). Workman and Twomey (1970) found that the respiration rates were consistently lower at 5 °C than at 20 °C.

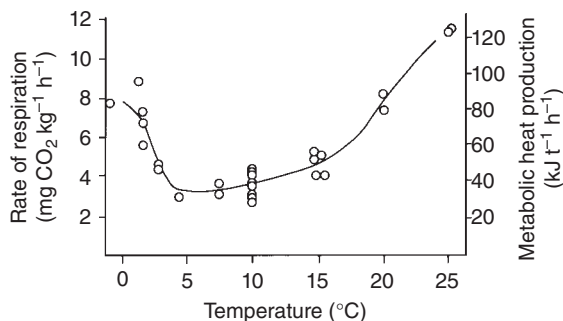


Figure 49 Respiration rate of potato tubers at various temperatures. (Source: Burton 1989a.)

Gas levels in stores

CO₂ accumulates naturally in potato stores through tuber respiration and is reduced either by air leakage or ventilation. Insufficient ventilation may increase the CO₂ concentrations to damaging levels. Vendelbo (1980) in his survey in commercial potato stores found a maximum of 3.5% CO₂ and up to 7.5% in pilot stores. In later work, Mazza and Siemens (1990) studied atmospheric CO₂ content in 18 commercial potato storage bins each containing 500–2500 tonnes of the cultivars Russet Burbank, Norchip, Kennebec and Monona in the United States. CO₂ concentration in the storage bins tested ranged from 0.06 to 3.2%. Stores containing Norchip had lower CO₂ levels than those with Russet Burbank probably due to differences in maturity and bruising at harvest. Values higher than 1% were found in about 50% of the storage bins in the 1986–1987 season but in none in the 1987–1988 season. The highest CO₂ levels occurred primarily during the curing period and during application of the sprout inhibitor CIPC. Varns (1986) measured CO₂ in an unventilated commercial potato stores during the curing period and found concentrations between 4 and 6%. Bishop (1992) found CO₂ levels between 0.6 and 1.6% in commercial stores in the United Kingdom. When these levels were reproduced in simulated stores at 4, 9 or 25 °C they found that there was a small increase in tuber sprouting. In some modern potato stores CO₂ analysers are fitted that are linked to the ventilation systems that are set to introduce ambient air when the CO₂ level reaches a certain level.

CO₂ has been shown to affect storage life and the influence of CO₂ on changes in respiratory metabolism of whole tubers may be one of the most important processes associated with the metabolic effect of CO₂. It might be that the changes are especially dependent on the concentration, exposure time, temperature and physiological age of tubers (Harris 1992). Published observations on the effect of CO₂ on the sprouting of potatoes are contradictory. In much published work CO₂ has been shown to inhibit or retard sprouting. Kardos and Blood (1947) showed a retarding effect on sprout growth when respiratory CO₂ was allowed to accumulate in stores to 12%. In an atmosphere containing 15% CO₂ Smith (1977) reported that sprout growth in tubers could be inhibited at 10 °C. Schmitz (1991) obtained promising results on sprout inhibition in an

atmosphere containing 8–12% CO₂ at 7 °C in Bintje and Saturna stored at both 6 and 10 °C.

In earlier work Kidd (1919) and Thornton (1939) using 2–6% O₂ and 20% CO₂ reported a stimulatory effect of these gas mixtures on sprouting of potato tubers. Braun (1931) found sprouting to be significantly stimulated at 2.2–9.1% CO₂. Burton (1952) also showed that sprouting was increased by passing the gas mixture containing 6.8% CO₂ continuously over the tubers. Later Burton (1958) confirmed the earlier findings that sprout growth was stimulated at 10 °C by increasing the concentration of CO₂ in the atmosphere with an optimal concentration of about 2–4% but at this level the concentration in the cell sap would be 0.04–0.05 ml CO₂ ml⁻¹. Concentrations above this had a progressively less stimulating effect. Schouten (1992) found that an atmosphere containing either 6% CO₂ with 5% O₂ or 3% CO₂ with 18% O₂ strongly stimulated sprout growth in tubers of the cultivar Agria stored at 6 °C for 3 months.

The effect of O₂ has also been shown by other workers to have an effect on sprouting. In Agria sprout growth was strongly inhibited in 0.7% O₂ and stimulated in 1.4 and 2.1% O₂ compared with air (Schouten 1992). According to Rakitin and Suvorov (1935), the growth of potato tuber buds was stimulated by exposure for 1 week to anaerobic conditions. Thornton (1939) found that sprouting could be induced in freshly harvested tubers, for three cultivars, if the concentration of O₂ in the storage atmosphere was reduced to 2%. Burton (1968) also found 2–4% O₂ to stimulate the growth of dormant buds. He suggested that these effects of O₂ may be concerned with the optimally anaerobic (and reversible) metabolism of a growth inhibitor. Burton (1973) found that exposure of the tubers to 1% O₂ for a few days at 10 °C, at the beginning of storage, stimulated subsequent sprout growth in air. Workman and Twomey (1969) found that after 10 months of storage in 1% O₂ at 4–5 °C the buds of seed potatoes were still viable. It was reported that sprout growth was strongly inhibited at 6 °C in 1% O₂ but at O₂ levels of about 5% sprout growth was stimulated at both 5 and 10 °C (Lipton 1967, Sherman and Ewing 1983, Schouten 1992). Burton (1952) measured the respiratory quotient in the presence of 5–7% CO₂ over a period of 11–14 weeks at 10 °C. The increased CO₂ reduced both O₂ uptake and CO₂ output by about 25–30%, but the respiratory quotient was unaffected and remained close to 1. Workman

and Twomey (1970) reported similar findings, when atmospheres in the range 4–12% CO₂ and 2 and 4% O₂ were used. At both 5 and 20 °C increasing CO₂ consistently increased tuber respiration. Perez Trejo *et al.* (1981), however, found that the application of high CO₂ concentrations in a range 3–30%, to whole potato tubers at room temperature, gave a pronounced increase in respiratory gas exchange, which persisted for at least 48 h at the beginning of storage.

In an atmosphere containing 5% O₂ and above, Harkett (1971) found that the CO₂ production of tubers increased rapidly to a maximum after 9–10 days and then fell slowly to near the initial level. At 40 and 100% O₂, the same author found the peaks of CO₂ production of the tubers reached 4.0 ml and 3.7 ml kg⁻¹ h⁻¹, respectively. Sherman and Ewing (1983) reported low levels of CO₂ output from tubers stored for 5 weeks in 2.5% O₂ at 1 and 10 °C. The gaseous atmosphere in which tubers are stored can affect their respiration rate. Generally low levels of O₂ and high levels of CO₂ reduce respiration rate (Thompson 2010). However, Pal and Buescher (1993) described experiments in which Russet potatoes were held in air or in controlled atmospheres containing 10, 20 or 30% CO₂ and found that short-term exposure to 20 and 30% CO₂ resulted in an increased respiration rate.

High oxygen storage

Exposure of potato tubers for some hours to pure O₂ had little or no effect on respiration rate. However, prolonged exposure led at first to an increase in CO₂ output, over a period of 2 weeks or so, but thereafter the effects of 'O₂ poisoning' became apparent and after 5–6 weeks respiration rate may be negligible (Barker and Mapson 1955).

Storage structures

Potatoes are stored in various ways with bulk stores being the most economic since more tubers can be fitted into a given space and it saves on the cost of boxes (Figure 50). Pallet boxes that contain up to 1 tonne of tubers are also used that are stacked in a store with baffles to ensure that air is circulated through each box. Tubers are also stored in sacks, which have the negative effects of being difficult to stack to the full height of the store room and also are difficult to ensure air circulation to the centre



Figure 50 Bulk potato store being loaded in Turkey.

of each bag. In the Sudan one company used this method because several growers stored their potatoes in the store and it was important to be able to identify which potatoes belonged to which grower. Tubers stored in bulk can suffer from compression damage or crushing and is found in the lower layers of potatoes in bulk stores. This is where the downward force on the crop is above a threshold level resulting in bruising. This often results in the physiological disorder called blackspot. This damage may also be a function of time, especially where the pressure is close to the threshold value. Usually the depth of bulk storage is up to $3\frac{1}{2}$ m but there are differences between cultivars in their susceptibility to compression damage. It may also be related to their moisture content, the higher their moisture content the more they are susceptible, which, in turn, may be related to preharvest cultural effects. Where bulk bins are used compression damage may be as a result of overfilling boxes and then stacking the boxes so that the crop in the lower boxes supports the weight.

Storage recommendations

The cultivar Russet Burbank and new frozen-processing cultivars, Umatilla Russet and Ranger Russet sweetened rapidly when exposed to 4.5°C but storage for 1 month at 6.7 and 9°C decreased the extent of low-temperature sweetening during subsequent storage at 4.5°C through most of the storage season (Knowles *et al.* 2009). At room temperature of 20°C and 60% r.h. it was reported in Mercantilia (1989) that tubers could be kept for about 3 weeks.

General refrigerated storage recommendations are as follows:

- 4°C and 95–98% r.h. for 240 days (Mercantilia 1989);
- 8°C for 120 days (Mercantilia 1989);
- 4°C and 90–95% r.h. for 4–5 months for potatoes grown in the southern United States (Holmes and Kemble 2009).

Refrigerated storage recommendations for different types and uses were as follows:

Immature or Early Cultivars

- $3\text{--}4^{\circ}\text{C}$ and 85–90% r.h. for a few weeks (Anonymous 1967);
- 10°C and 85–90% r.h. for a few days (Phillips and Armstrong 1967);
- 10°C and 90% r.h. for 3 months (Lutz and Hardenburg 1968);
- $4\text{--}5^{\circ}\text{C}$ and 90–95% r.h. for 3–8 weeks (Snowdon 1991);

Late or Ware Cultivars

- $3\text{--}4^{\circ}\text{C}$ and 85–90% r.h. for a few weeks (Anonymous 1967);
- 10°C and 85–90% r.h. for a few days (Phillips and Armstrong 1967);
- 10°C and 90% r.h. for 3 months (Lutz and Hardenburg 1968).

For Processing

- $15.6\text{--}21.1^{\circ}\text{C}$ and 85–90% r.h. for a few days for early cultivars (Phillips and Armstrong 1967);
- 10°C and 90–95% r.h. for 56–175 days (for processing) (SeaLand 1991);
- $7\text{--}8^{\circ}\text{C}$ and 90–95% r.h. for 6–9 months (for processing into chips) (Snowdon 1991);
- $8\text{--}9^{\circ}\text{C}$ and 90–95% r.h. for 6–9 months (for processing into crisps) (Snowdon 1991);

For Seed

- $2.2\text{--}3.3^{\circ}\text{C}$ and 85–90% r.h. (Phillips and Armstrong 1967);
- $2\text{--}7^{\circ}\text{C}$ and 85–90% r.h. for 5–8 months (Anonymous 1967);
- $3.3\text{--}4.4^{\circ}\text{C}$ and 85% r.h. for 34 weeks with 4.9% loss (Pantastico 1975);
- 4.4°C and 90–95% r.h. for 84–173 days (SeaLand 1991).

Table 106 Sugar content of tubers from three potato cultivars after being stored for 25 weeks in 9.4% CO₂ + 3.7% O₂ then another 20 weeks in air all at 5 °C (source: adapted from Khanbari and Thompson 1996)

Reconditioning	Cultivars	Type of sugar g 100 g ⁻¹ dry weight			Grey level ^a
		Fructose	Glucose	Sucrose	
No	Record	0.78	0.85	0.52	130
No	Saturna	0.66	0.69	0.54	137
No	Hermes	0.98	1.12	0.56	123
Yes	Record	0.63	0.56	0.90	133
Yes	Saturna	0.38	0.34	0.49	152
Yes	Hermes	1.03	1.13	1.13	124

Reconditioned was for 2 weeks at 20 °C after 45 weeks of storage.

^aThis is for the crisps processed from the potatoes above. Minimum acceptable grey level = 149 or above (Figure 51).

Controlled atmosphere storage

As described above the amount of O₂ and CO₂ in the atmosphere of a potato store can affect the sprouting, rotting, physiological disorders respiration rate sugar content and processing quality of tubers (Table 106). Fellows (1988) recommended 10% CO₂ and a minimum of 10% O₂. CA has been reported to affect the mechanical properties of tubers. Olsen *et al.* (2003) reported that it appeared that tubers prior to storage had quantitatively stronger tissue compared to tubers after storage. They found that after storage at 7 °C in 2% O₂ + 10% CO₂ altered tissue mechanical properties as well as carbohydrate content and had physiochemical characteristics of tubers stored at 3 °C in air. Where the O₂ concentration is too low in store the odour of the tubers can be affected. Lipton (1967) found that White Rose tubers stored at 0.5% O₂ had a sour off-odour when raw and this off-odour persisted when cooked. Aeration for 8 days following 0.5% O₂ storage diminished this off-odour and off-flavour. The taste was influenced only slightly at 1% O₂ and no off-odour or off-flavour was found in tubers stored in 5% O₂.

CA on sugars and processing

If potatoes are to be processed into crisps or chips it is important that the levels of reducing sugars and amino acids are at a level to permit the Maillard reaction during frying. This gives them an attractive golden colour and their characteristic flavour. If levels of reducing sugars are too high they are too dark after frying and unacceptable to the processing industry and this colour change of processed crisps was described by Khanbari (1995) and presented as a colour chart (Figure 51). Potatoes stored



Figure 51 Colour chart used for assessing fry colour of potatoes.

at temperatures around 4 °C have higher levels of sugars than those stored at higher temperatures of 7–10 °C (Khanbari and Thompson 1994) which can result in the production of dark coloured crisps. At low storage temperatures, potato tubers accumulate reducing sugars, but the effects of CO₂ can influence their sugar levels. Workman and Twomey (1969) reported that storage in 4% CO₂ resulted in higher reducing sugars than in air. Denny and Thornton (1941) had previously reported that 5% CO₂ prevented accumulation of reducing sugars but increased accumulation of sucrose. Reust *et al.* (1984) found an accumulation of sugars especially sucrose in storage with 6% CO₂. However, Burton (1989a) in a review reported an initial reduction in reducing sugars but later increase to a higher level than air. With levels of 6% CO₂ + 2–15% O₂ in storage for 178 days at 8 and 10 °C fry colour was very dark (Reust *et al.* 1984). Mazza and Siemens (1990) studying 1–3.2%

CO₂ found that darkening of crisps occurred after there was a rise in CO₂ levels in stores. At levels of CO₂ of 8–12% the fry colour was darker than for tubers stored in air (Schmitz 1991). At O₂ levels of 2% reducing sugar levels were reduced or there was no accumulation at low temperature, but 5% O₂ was much less effective (Workman and Twomey 1969). The cultivar Bintje were stored at 6 °C in atmospheres containing 0, 3, 6 or 9% CO₂ and 21, 18, 15 or 12% O₂. During the early phase the unfavourable effect of high CO₂ on fry colour increased to a maximum at 3 months. In the later phase fry colour deteriorated in tubers stored in zero CO₂ and CO₂ enrichment had less effect (Schouten 1994). Khanbari and Thompson (1994) stored Record tubers at 4 °C in 0.7–1.8% CO₂ + 2.1–3.9% O₂ and found that it resulted in a significantly lighter crisp colour, low sprout growth and fewer rotted tubers compared with air. Storing tubers in anaerobic conditions of total N₂ prevented accumulation of sugars at low temperature but it had undesirable side effects of the tubers (Harkett 1971). Gökmen *et al.* (2007) stored tubers of Agria and Russet Burbank at 9 ± 1 °C and found that there was only a limited increase in the concentrations of sugars during 6-month storage in air but in controlled atmosphere storage where the O₂ level was sufficiently low to increase the respiration rate of the concentrations of sugars increased.

CA on sprouting and disease

Schouten (1992) discussed the effects of controlled atmosphere storage on sprouting of stored potatoes. He found that sprout growth was stimulated in 3% CO₂ at 6 °C, whereas some inhibition of growth occurred in 6% CO₂. Sprout growth was strongly inhibited in 1% O₂ at 6 °C, but pathological breakdown may develop at this O₂ level. Internal disorders were found at O₂ levels of less than 1%. Stimulation of sprout growth occurred at slightly higher O₂ levels if controlled atmosphere storage started from the beginning of the season. Stimulation was less if low O₂ conditions were applied from January onwards in Holland. It was concluded that CA storage at 6 °C was not an alternative to chemical control of sprout growth for potatoes used for consumption. In the early phase of storage Schouten (1994) showed that sprouting was stimulated by 3–6% CO₂ and inhibited by 9% CO₂. During the later phase all CO₂ concentrations inhibited sprouting. Khanbari and

Thompson (1994) showed that high CO₂ with low O₂ combinations during storage completely inhibited sprout growth but caused the darkest colour when they were processed into crisps. However, after reconditioning tubers gave the same level of sprouting and crisps as light as the other controlled atmosphere storage combination. Reconditioning of stored tubers can reduce their sugar content (Table 106) and improve their fry colour (Khanbari and Thompson 2004). Schouten (1994) recommended reconditioning tubers at 15 °C for 2–4 weeks and showed that the treatment improved crisp fry colour, but he also found that reconditioning stimulated sprouting. Tubers stored in of 0.7–1.8% CO₂ + 2.1–3.9% O₂ showed a significantly higher weight loss and shrinkage after reconditioning compared to tubers which had previously been stored in air (Khanbari and Thompson 1994). They also slowed that tubers stored in high CO₂, especially at 10 or 15%, had earlier onset of rotting. At 0.7–1.6% CO₂ + 2–2.4% O₂ there was also an increase in tuber rotting.

Hypobaric storage

Burg (2004) reported that greening was inhibited in tubers stored at 15 °C and 126 mm Hg in the light but there was no effect on their solanine content. Similar results were also reported during storage at 2½, 5, 10 or 20 °C and 76–95 mm Hg and in controlled atmosphere storage with 2–2½% O₂.

Reconditioning

Reconditioning of stored potato tubers is exposing them to higher temperatures for a period after storage and before processing, which hastened catabolism of reducing sugars and restoration of processing quality (Knowles *et al.* 2009). Recommendations for reconditioning have varied (Table 107) but they are mainly between 15 and 25 °C with a shorter time being necessary at the higher temperatures. Reconditioning has been shown to reduce their sugar content (Table 106) and improve their fry colour (Khanbari and Thompson 1996). Schouten (1994) showed that reconditioning improved chip fry colour, but stimulated sprouting. Choi *et al.* (1997) also showed that reconditioning hastened tuber sprouting of the cultivars Atlantic and Superior grown in Korea when stored at 5 °C for 90 days and reconditioned at 15 °C

Table 107 Conditions given in some recent research publications which were found to be suitable for reconditioning potato tubers after low-temperature storage

Reconditioning conditions	References
15 °C for 20 days	Kim <i>et al.</i> (1993)
15 °C	Choi <i>et al.</i> (1997)
15 °C for 2–4 weeks	Schouten (1994)
18 °C for at least 2 weeks	Gichohi and Pritchard (1995)
18 °C for 6 weeks	Gounaris and Sowokinos (1992)
18–20 °C for 3 weeks	Thill and Peloquin (1994)
18–20 °C for up to 4 weeks	Harvey <i>et al.</i> (1998)
20 °C	Brierley <i>et al.</i> (1996)
20 °C for 10–12 days	Timm <i>et al.</i> (1968)
20 °C for 2 weeks	Pereira <i>et al.</i> (1993)
20 °C and 90–95% r.h. for 2 weeks	Khanbari and Thompson (1994)
20 °C for 3 weeks	Carey and Cronin (1990)
20 °C for 4 weeks	Maag and Reust (1992)
20 °C for 6 weeks	Williams and Cobb (1992)
25 °C	Hagen and Muneta (1993)
25 °C for 2 weeks	Okeyo and Kushad (1995)
25 °C for 20 days	Jeong <i>et al.</i> (1996)
12 °C for 17 days	Knowles <i>et al.</i> (2009)

for as long as 90 days. Using a reducing sugar content of 0.25% as the limit of acceptability, reconditioning studies showed that storage at 10 °C maintained contents below this level for up to 120 days of storage and at this level up to 150 days of storage. In contrast Jeong *et al.* (1996) found that reconditioning after storage at 4 °C could not maintain the reducing sugar content below 0.25% even at the early stage of storage.

Coatings

Use of Nature Seal 1020, a cellulose-based edible coating, as carrier of antioxidants, acidulants and preservatives prolonged the storage life of cut potato cultivar Russet by about 1 week when stored in over wrapped trays at 4 °C. Similarly, the preservatives sodium benzoate and potassium sorbate were more effective in controlling certain microbial populations when applied in Nature Seal than in aqueous solutions, but less effective for others. Adjustment of coating pH to 2.5 gave optimal control of browning and microbial populations. Addition of soy protein to the original cellulose-based Nature Seal formulations reduced coating permeability to O₂ and water vapour. Cellulose formulations with protein were effective in controlling weight loss, especially when the pH of the

formulation was raised above that of the isoelectric point of the protein (Baldwin *et al.* 1996). Surface Systems International developed a formulation of carboxy methyl cellulose and sucrose esters, which was claimed can be applied as a coating to tubers to control sprouting during storage.

The effects of light on greening and visual external quality of tubers of the cultivars Atlantic and Cadima which had been coated with various protective coating solutions (3% sweetpotato flour, 3% tapioca flour, 3% arrowroot flour, 3% gelatin, 1.5% Semperfresh, Ausgloss and LDPE bag) were investigated. Ausgloss and gelatin solution coating reduced the degree of greening and hence improved tuber quality when they were placed under constant light (Tan and Haynes 1996).

Processing

If potatoes are to be processed into crisps or chips it is important that the levels of reducing sugars and amino acids are at a level to permit the Maillard reaction during frying. This gives them an attractive golden colour and their characteristic flavour. If levels of reducing sugars are too high the crisps or chips are too dark after frying and may be unacceptable to the processing industry (Roe *et al.* 1990, Shallenberger *et al.* 1959). Potatoes stored at low temperatures of around 4 °C have higher levels of sugars than those stored at higher temperatures of 7–10 °C (Khanbari and Thompson 1994) but the levels of CO₂ in the store can also influence their sugar levels. With 6% CO₂ + 2–15% O₂ in store during 178 days at 8 and 10 °C Reust *et al.* (1984) found that fry colour was very dark.

At 2% O₂ reducing sugar levels were reduced or there was no accumulation at low temperature, but 5% O₂ was much less effective (Workman and Twomey 1969). The cultivar Bintje was stored at 6 °C in atmospheres containing 0, 3, 6 or 9% CO₂ and 21, 18, 15 or 12% O₂. During the early phase the unfavourable effect of high CO₂ concentration on chip colour increased to a maximum at 3 months. In the later phase chip colour was also dark in tubers stored without CO₂ and CO₂ enrichment had less effect (Schouten 1994). Khanbari and Thompson (1994) stored Record tubers at 4 °C in CO₂ levels of 0.7–1.8% with 2.1–3.9% O₂ and found that this combination resulted in a significantly lighter

crisp colour, low sprout growth and fewer rotted tubers compared with storage in air. Schouten (1994) described an experiment where tubers of cultivar Bintje were stored at 6 °C in atmospheres containing 0, 3, 6 or 9% CO₂ and 21, 18, 15 or 12% O₂ and chip colour was determined at intervals during early and late phases of storage. During the early phase the unfavourable effect of high CO₂ concentration on chip colour increased to a maximum at 3 months. In the later phase chip colour deteriorated in tubers stored without CO₂ and CO₂ enrichment had relatively less effect. In Korea tubers of cultivar Superior stored at a constant 15 °C maintained adequate levels of reducing sugars acceptable for processing as chips (Choi *et al.* 1997). Storing tubers in anaerobic conditions of total N prevented accumulation of sugars at low temperature but it had undesirable side effects of the tubers (Harkett 1971). At 6% CO₂ and 15% O₂, Reust *et al.* (1984) found, after 178 days of storage at 8 and 10 °C, that the culinary quality of the potato tubers was seriously affected. On the other hand, Mazza and Siemens (1990), in their survey on the CO₂ concentrations on commercial potato stores and its effect on crisps quality, reported a darkening of the crisps made from the tubers immediately after rises in CO₂ concentration, from 1 to 3.2%. Schmitz (1991) observed an obvious reduction in processing quality, when 8–12% CO₂ are used on stored potatoes at 8 °C, and darker crisps were obtained after frying. Schwobe and Parkin (1990) observed a decline in the colour value of processed potatoes with a subsequent increase in hexoses and fall in sucrose content. They also found that storage of the cv Norgold in low O₂ (3%) reduced the maximum levels of sucrose accumulation. For the cv Russet, the low-O₂ atmosphere reduced both maximum extent and rate of sucrose accumulation and an acceptable chip (crisp) colour was maintained after 6 weeks of storage at 3 °C. Dark coloured crisps were obtained when potato tubers were stored in an atmosphere of 6% CO₂ + 15% O₂ for 3 and 6 months at 6 °C (Schouten 1992).

Browning and crisp quality

Colour is a very important visual criterion for marketing potato crisps. The most important problem in the potato crisp industry, therefore, is the maintenance of desirable colour throughout the processing season. Control of colour, which is necessary for a standard product quality, is difficult because

the colour of the potato crisps is determined by the chemical composition of the tubers (Smith and Thompson 1987). Tuber composition, however, is influenced by a number of factors, including variety, tuber maturity and temperature, in addition to many uncontrollable environmental factors in the field and also conditions during transit and storage (Talbert and Smith 1987). The food manufacturers are interested in the non-enzymatic browning reactions and concern how they can aid in the production of food of superior quality. In order to achieve this, the factors that affect the reaction must be understood, the most important determinants being temperature, time, composition of the system, water activity (*aw*), pH and sulphur dioxide (Nursten 1986). In fact, the non-enzymatic browning (Maillard) reactions are made up of thousands of individual reactions, each of which is influenced in different ways by the factors listed above (Reineccius 1990). To correlate crisp colour with tuber composition, previous research has concentrated on total reducing sugar content. Little data are available on the levels of the major individual sugars, glucose, fructose and sucrose, in known poor and good crisping cultivars. In addition, the change in the levels of the major tuber sugars during the harvesting period has not been well established (Miller *et al.* 1975). Further investigations by Sowokinos (1978) described a standard sucrose rating procedure to detect rapidly annual variation in processing potato maturity to aid in determining proper postharvest storage and utilization practices. The organic N fraction contains free amino acids, and the amides, glutamine and asparagine. These compounds account for an important part of the total fraction. The free amino acid content may vary among cultivars, year of cultivation, soil type, fertilizer application, climate, origin and storage condition (Talley and Porter 1970, Davies 1977). The composition of the free amino acid fraction is given in Table 108.

The Maillard reaction is the principal type of non-enzymatic browning which occurs when virtually all foods are heated (Ames 1990). It also occurs during the storage of certain commodities at, or below, room temperature. The non-enzymatic browning reactions usually involve the reaction of carbonyl groups with free amino groups, but similar reactions (carmelization) occur in the absence of amino compounds, but at higher temperatures. As far as the manufacturer is concerned, the most

Table 108 Free amino acids of potato tubers in milligram amino acid 100 g⁻¹ tuber dry matter (source: adapted from Davies 1977)

Amino acid	Cultivar					
	Record		Alpha		Bintje	
	1969	1970 ^a	1969	1970	1969	1970
Aspartic acid	259	199–379	247	233	197	249
Asparagine	1937	1200–2594	1159	1947	1230	2554
Threonine	69	40–103	39	34	45	63
Serine	63	43–83	47	53	44	47
Glutamine	1479	973–2050	871	1260	984	1861
Proline	130	42–303	62	201	49	297
Glycine	11	7–18	9	–	9	20
Alanine	24	23–25	24	30	36	118
Valine	152	74–281	60	182	110	220
Methionine	48	32–64	55	56	51	72
Isoleucine	58	42–88	45	52	59	67
Leucine	33	25–38	16	–	31	44
Phenylalanine	81	49–102	56	50	55	27
Tryptophan	–	42	–	–	145	–
Lysine	52	33–64	39	75	32	45
Histidine	163	85–247	62	107	91	183
Arginine	434	258–670	181	298	143	280
4-Aminobutyric	171	49–326	66	310	146	442
Ornithine	–	26	–	–	–	–

^aWhere there were three or more samples of the same cultivar, the average and range are reported.

significant and obvious effects of the Maillard reaction are the development of colour and flavour. Most of the effects of the reaction, such as the golden colours or caramel aromas that develop on heating, are desirable. Nevertheless, the Maillard reaction is sometimes undesirable (e.g. when potato crisps darken and develop off-flavour on storage). The Maillard reaction may also result in a reduction in nutritional value, the development of antioxidant properties and the formation of potentially toxic compounds (Nursten 1980, 1981, cited by Ames 1990).

An outline of the Maillard reaction was presented and illustrated by Ames (1990) and Nursten (1986). It involves condensation of the carbonyl group of a reducing sugar (aldose) with a free amino group of a protein or amino acid to give an *N*-substituted glycosylamine (Step A), which rearranges to form the Amadori Rearrangement Product (ARP) (Step B). The ARP dehydrates to form furfurals and reductones (Step C) and/or fission dicarbonyl products (Step D). These compounds, and the aldehydes formed by Strecker degradation of amino acids (Step F), may react either in the absence of amino compounds, to

give brown nitrogenous polymers and copolymers, called melanoidins (Step G). Another route (Step H) provides a direct way to fission products from *N*-substituted glycosylamines, without the formation of an ARP. Some steps of the Maillard reaction are well defined, leading to the formation of volatile aroma components. The reactions leading to the development of non-volatile colour compounds (mainly outlined by Steps F and G) remain obscure (Ames 1990).

In the potato industry, the browning of crisps and French fries at high processing temperatures is due to a typical Maillard reaction between reducing sugars and the alpha-amino groups of nitrogenous compounds (Shallenberger *et al.* 1959). In practice, the quantities of amino-N are rarely limiting and the extent of browning is better correlated with the concentration of the principal reducing sugars, glucose and fructose (Gray and Hughes 1978). Their levels are used by the industry as a predictive test of the suitability of material for processing. This has not always been satisfactory, however, and processors have found that some material develops a fry colour different from that which would be expected based

on reducing sugar content. This deviation from the expected colour has been ascribed to the free amino acid concentration in the potato (Roe *et al.* 1990). The ideal reducing sugar content for processing into crisps is generally accepted to be 0.1% of tuber fresh weight with 0.33% as the upper limit. For French fries, the upper limit may be as high as 0.5% (Burton and Wilson 1970).

Many Maillard browning studies were conducted using aqueous model systems, filter paper discs (Shallenberger 1955), and recently radio-labelled amino acids were used, which offer a method of establishing whether or not part of the amino acid structure is indeed incorporated into the brown pigment (Adams 1991).

Temperature

This has been dealt with under postharvest physiology. Nakagawa *et al.* (1995) showed that the total sugar content of tubers stored at 22 °C was low, whereas at 4 or 33 °C it increased rapidly to about 2%. Reducing sugar content of tubers stored at 33 °C was lower than at 4 °C. Therefore for tubers destined to be processed into crisps or chips storage temperatures of between 7 and 10 °C are commonly recommended. There was very little sprouting after storage at 2 °C for 9 months but sugar contents increased in three cultivars tested, Wu-Foon, Cardinal and Kennebec, and were greatest in Wu-Foon (Liu *et al.* 1989). Temperatures of less than 8 °C are associated with increased reducing sugar contents in tubers, which produce dark-coloured substances with a bitter taste via the Maillard reaction in processed potatoes (Grassert and Schuler 1993). Storing potato tubers in anaerobic conditions of total N prevented accumulation of sugars at low temperature (Harkett 1971).

Cultivar

Hexose accumulation in storage has been shown to be cultivar dependent and proposed to be the result of sucrose hydrolysis via invertase. To study whether hexose accumulation is indeed related to the amount of invertase (β -fructofuranosidase) activities, two different approaches were used: (i) neutral and acidic invertase activities and TSS were measured in cold-stored tubers of 24 potato cultivars differing in the cold-induced accumulation of reducing sugars and (ii) antisense potato plants with reduced soluble acid invertase activities were created and the soluble

sugar accumulation in cold-stored tubers was studied. The cold-induced hexose accumulation in tubers from the different potato cultivars varied strongly (up to eightfold). Large differences were also detected with respect to soluble acid (50-fold) and neutral (fivefold) invertase activities among the different cultivars. Although there was almost no correlation between the total amount of invertase activity and the accumulation of reducing sugars there was a striking correlation between the hexose/sucrose ratio and the extractable soluble invertase activity. To exclude the possibility that other cultivar-specific features could account for the obtained results, the antisense approach was used to decrease the amount of soluble acid invertase activity in a uniform genetic background. To this end the cDNA of a cold-inducible soluble acid invertase (EMBL nucleic acid database accession no. X70368) was cloned from the cultivar Desiree, and transgenic potato plants were created expressing this cDNA in the antisense orientation under control of the constitutive 35S cauliflower mosaic virus promoter. Analysis of the harvested and cold-stored tubers showed that inhibition of the soluble acid invertase activity leads to a decreased hexose and an increased sucrose content compared with controls. As was already found for the different potato cultivars the hexose/sucrose ratio decreased with decreasing invertase activities but the total amount of soluble sugars did not significantly change. From these data it is concluded that invertases do not control the total amount of soluble sugars in cold-stored potato tubers but are involved in the regulation of the ratio of hexose to sucrose (Zrenner *et al.* 1996).

Breeding for reduced sweetening of tubers during storage at 4 °C was reviewed by Davies and Mackay (1994). Information is presented on the intercrossing of sugar stable clones with commercial cultivars including Record and Pentland Dell and work on protoplast fusion of *S. tuberosum* and *S. phureja* (which is reported to have low-temperature sugar stable genotypes). The cultivar Brodick has been reported to be sugar stable. Gounaris and Sowokinos (1992) also showed that different cultivars accumulated different sugar levels during storage. The cultivars used in storage were ND 860-2, ND651-9, Kennebec and Russet Burbank of which ND 860-2 was said to be low sugar accumulating. The cultivar Superior was stored at 5 °C for 28 days and was then reconditioned at 15 °C for 20 days. The reducing sugar content decreased

slowly during the reconditioning period. The longer the reconditioning period, the better the potato chip colour (Kim *et al.* 1993).

Progenies from crosses of ND860-2, a low reducing sugar clone, with potato cultivars Trent and Onaway, differing in reducing sugar content, as well as the progenies of the parents that had been selfed, were examined for reducing sugar content. Tubers were assessed after storage at 12 °C for 10 weeks (regular storage) and 4 °C for 10 weeks followed by reconditioning at 20 °C for 2 weeks (reconditioning). After regular storage, all seedling progenies had relatively high frequencies of low reducing sugar segregates (i.e. equal or less than those of ND860-2). After reconditioning, a high frequency of seedlings with low reducing sugars was observed in the progeny from ND860-2 X Trent (46.7%); however, they were also found in the progeny from ND860-2 X Onaway (6.7%). Results of this study suggested that progenies from crosses involving ND860-2 would segregate for low reducing sugar content regardless of the reducing sugar level of the other parent (Pereira *et al.* 1993).

Screening trials were carried out to select cultivars with potential cold storing ability. Medium-sized tubers of cultivar Torva, Fecuva, Palma, Hutten, BRA 15/33, Freika, Allagash Russet, Laverta, Bevelander, BRA C 676/41, Fecula, Hokkaiaka, Iduna, Prumex, Sowa, Loschitzki, Endra, Rode Star and Herbstfreude were stored at 3–4 °C and 90% r.h., from September to April. Reducing sugar contents ranged from 0.29 to 0.59%, with the lowest quantities found in cultivar Palma, Fecula, Freika and Allagash Russet. Crisps produced from tubers at the end of storage showed discolouration in all cultivars, and only 1.5% of deep-fried tuber samples were of medium processing quality. It is concluded that cold storing quality of the cultivars tested is too low for use in a breeding programme on this trait (Grassert and Schuler 1993).

MaineChip is medium-maturing and has round, white-skinned, white-fleshed tubers with shallow eyes, high specific gravity and moderate yields (24.5 tonnes ha⁻¹ during 1989–1991). It was bred for use as a storage chipping cultivar as sugar build up in storage is slow and reconditioning is possible. This cultivar can be chipped directly from 7 °C storage. MaineChip does not show the net necrosis caused by potato leafroll luteovirus and is moderately tolerant of *Verticillium albo-atrum*, *Rhizoctonia solani*, black spot and shatter bruise; however, hollow heart was

noted as a problem in 10 of the 29 regional tests conducted during 1987–1991 (Reeves *et al.* 1994).

More than 600 potato cultivars and selections held by the New Zealand Institute for Crop and Food Research Limited were screened by Harvey *et al.* (1998) over three seasons to identify material with resistance to cold-induced sweetening. Potato lines were tested 1–2 weeks after harvest and those with glucose levels below 0.1% in the potato juices were stored at 4 °C for 2 and 4 months. Tubers, which failed to produce crisps of an acceptable colour, were reconditioned at 18–20 °C for up to 4 weeks and re-tested. Lines with potential to resist cold-induced sweetening or with reconditioning potential were re-tested for an additional two seasons. Over the three seasons, the following three cultivars and four breeding selections consistently produced the lightest coloured crisps: ADX248-16, ND860-2, Red Dakota and Atlantic from the United States and Torridon, V99 and V489 from the United Kingdom. Lines that improved to an acceptable reducing sugar level after reconditioning were Agria, Fianna and Darwina from the Netherlands; Lindsey, V401, V402 and V424 from the United Kingdom and Gladiator, 1975.12, 354/12 and 472/8 from Crop and Food Research Limited. Tubers of six potato cultivars were stored at 4, 10 or 25 °C for up to 180 days, with reconditioning at 25 °C for 20 days of some of the tubers in the 4 and 10 °C treatments after different storage durations. In spite of the lower sugar accumulation, storage at 25 °C resulted in excessive weight loss and sprout growth from the early stage of storage. Storage at 4 °C resulted in an excessive accumulation of reducing sugars and continuous darkening of chip colour. It is therefore suggested that the storage temperature of potato tubers for processing should be kept at about 10 °C. Using a reducing sugar content of 0.25% as the limit of acceptability, the reconditioning studies showed that storage at 10 °C maintained contents below this level for up to 120 days of storage and at this level up to 150 days of storage. Reconditioning after storage at 4 °C could not maintain the reducing sugar content below 0.25% even at the early stage of storage.

Potato cultivar Pentland Dell and Record tubers were stored for a period of up to 40 weeks at 5 or 10 °C over four consecutive storage seasons by Brierley *et al.* (1996). Reconditioning treatments at 20° were also performed at early, mid and late stages in storage. To

assess the turnover of proteins during storage, tubers were analysed for free amino acid and soluble protein content. The net direction of N flow was dependent on the state of dormancy of the tuber and hence storage duration. An increase in free amino acid content commonly occurred during the latter part of storage, caused by an upturn of proteinase activity on the break of dormancy. This increased enzyme activity was probably due to *de novo* synthesis of proteinases, in particular of a 47-kDa aspartic proteinase which was purified to homogeneity and shown to have a marked substrate specificity for endogenous tuber proteins such as patatin. The rate of protein turnover increased with storage temperature, although the net direction of N flow was temperature independent. However, when N flow exhibited a distinct direction, such as the protein breakdown in Pentland Dell during late storage, this was enhanced by higher temperatures. The accumulation of free amino acids in Pentland Dell at 10° corresponded with a deterioration of processing quality that could not be accounted for by an upturn in reducing sugar content. Despite an excess of free amino acids with respect to reducing sugars, amino acids had a probable synergistic influence on fry colour over the later stages of storage resulting in a darker colour per unit reducing sugar than an early storage. Reconditioning treatments were ineffective as a means of lowering the free amino acid pool size, these treatments operating solely through the decrease in reducing sugar content.

Chemical treatments have been shown to affect the level of sugar accumulation during storage. Potato cultivar Diamant, Cardinal and Desiree tubers were treated with 1% sodium acetate (w/v) and placed in cold storage at 2–4 °C for up to 6 months. Compared with the untreated tubers, the total sugar content in the treated tubers was significantly lower (Ehteshamuddin *et al.* 1995).

Reducing sugar and sucrose contents of potato cultivar Record, Cara, Pentland Dell, Pentland Squire, Pentland Ivory and Maris Piper tubers were monitored both during the growing season and after a 4-month storage period at 10 °C. Significant correlations were found between tuber sugar contents (sucrose, reducing and total) measured at harvest and reducing sugar content after storage. In all cultivars except Pentland Ivory the sucrose loss and the corresponding reducing sugar gain during storage were

significantly correlated (Richardson *et al.* 1990a, 1990b).

Hill *et al.* (1996) conducted experiments to investigate events involved in triggering sugar accumulation in cold stored tubers of Desiree. After transfer to 4 °C net sucrose accumulation began between 2 and 4 days. By 10 days, reducing sugars were also increasing. From 20 days onwards, sugar accumulation slowed. Sucrose fell, but reducing sugars continued to increase. After 1 day at 4 °C, the rates of sucrose synthesis decreased compared to those at 20 °C. They also show that the final level of sugar is partly determined by a cycle of sugar synthesis and degradation. It is concluded that the onset of sugar accumulation in cold-stored tubers is initiated by a change in the kinetic properties of SPS and the appearance of a new amylolytic activity. Other factors, including hexose-phosphate levels and subcellular compartmentalization, could also influence the final levels of sugars by altering the balance of sugar synthesis and remobilization.

The process by which the accumulation of sugars occurs involves the interaction of many metabolic pathways and is yet to be fully described. Low-temperature conditions result in an accumulation of ATP in potato tubers. Published evidence suggests that low-temperature activation of the alternative pathway (cyanide-resistant respiration) leads to decreased ATP levels and simultaneous increases in sucrose concentrations. This sucrose becomes the substrate for vacuolar acid invertase (β -fructofuranosidase) resulting in the accumulation of reducing sugars. Inhibition of the alternative pathway results in decreased sugar accumulation thereby minimizing the sucrose available to the acid invertase and the subsequent reducing sugar accumulation. Control of the alternative pathway on its own, or in combination with acid invertase activity, may provide insight into the phenomenon of low-temperature sweetening in stored potato tubers (Duplessis *et al.* 1996).

Senescent sweetening

Levels of sugar in potato tubers vary with cultivar and growing conditions but they are also affected by storage temperature and time in storage. Senescent sweetening occurs when tubers have been stored for protracted periods. Williams and Cobb (1992) reported that during the 1990/1991 storage season,

the cultivar Pentland Dell exhibited senescent sweetening late in storage.

Conditioning

Preconditioning before storage

The potato cultivars Russet Burbank and Shepody with varying sucrose concentrations at harvest were preconditioned by holding at 15 °C for various durations to lower the reducing sugar concentration to levels acceptable for processing as French fries after storage at 8 °C. In tubers harvested with a high sucrose concentration, sucrose decreased after harvest and stabilized in storage regardless of the preconditioning period. However, there was a small temporary increase in sucrose after harvest in more mature tubers. Glucose and fructose concentrations were low at harvest, usually less than 1 mg g⁻¹, but increased rapidly during the first 30–45 days of storage in tubers with more than 2 mg g⁻¹ sucrose at harvest. Preconditioning for up to 70 days at 15 °C either limited the increase in reducing sugars or lowered them more rapidly during storage than when preconditioned for only 14 days. Fresh weight loss of Russet Burbank and Shepody was greater in physically and chemically immature tubers compared with more mature tubers. Extended preconditioning of Russet Burbank and Shepody resulted in minimal additional weight loss (Pritchard and Adam 1992).

Reconditioning after storage

Storing potatoes at temperatures below 7 °C can delay sprouting and other factors involved in deterioration, but it results in undesirably high sugar content. Reconditioning is exposing tubers which have been stored at low temperatures to higher temperatures to reduce their sugar content. This is important for tubers which are to be processed into crisps, chips or French fries. This process has been known for many years (Appelman 1912). Gounaris and Sowokinos (1992) reported that the accumulation of reducing sugars during storage at 3 °C for 5 months could be partially reversed by storage at 18 °C for the last 6 weeks. Liu *et al.* (1989) also showed that reconditioning decreased sugar content but the longer tubers were stored at low temperature the less the sugar content was reduced by reconditioning. Kim *et al.* (1993) showed that the reducing sugar content decreased slowly during the reconditioning period. The longer

the reconditioning period, the better the potato chip colour. Gichohi and Pritchard (1995) showed that the reducing sugars accumulated in Shepody during storage at 5 and 6 °C for about 24 weeks after harvest could be lowered to levels acceptable for processing by reconditioning at 18 °C for at least 2 weeks. Some cultivars respond more to reconditioning than others. Lines that improved to an acceptable reducing sugar level after reconditioning were Agria, Fianna, Darwina, Lindsey, V401, V402, V424, Gladiator, 1975.12, 354/12 and 472/8 (Harvey *et al.* 1998). In Pentland Dell and Record respiration rates were stimulated up to 200% by reconditioning with the majority of the response occurring within the first 2 weeks of the 6-week treatment at 20 °C. This increased respiration only accounted for the corresponding reducing sugar decline when the sugar pool size was relatively small (Williams and Cobb 1992).

The effects of storage at 2, 5 and 10 °C on sugar levels and chip colour were examined in potatoes cultivar Record and Glenroe. Storage at 10 °C was necessary to maintain the reducing sugar content of both cultivars at acceptable levels. For samples stored at 2 and 5 °C, reconditioning at 20 °C for 21 days was effective in lowering the reducing sugar content and in improving chip colour. Tubers of Glenroe responded more favourably in reconditioning than those of Record. The critical level above which tubers should be rejected for processing with the glucose-strip method was 0.10% glucose (Carey and Cronin 1990). Schouten (1994) found that reconditioning the tubers at 15 °C for 2–4 weeks slowly improved chip colour but stimulated sprouting.

Burton (1969) described experiments where tubers were stored in temperatures which fluctuated diurnally between 2 and 10 °C and found that the sugar content remained similar to those stored at higher temperatures (Table 109) while preventing sprouting. With modern computer controls it should be possible to achieve these conditions on a commercial scale, thus eliminating the need for chemical application to control sprouting. The optimum temperatures used for reconditioning vary depending on cultivar, time in storage, storage temperature and reconditioning time (Table 107).

Table 109 The effects of diurnal fluctuation in temperature on the sugar content of potato tubers stored for 20 weeks (source: adapted from Burton 1969)

Temperature regime	Total sugar (%)	
	Experiment 1	Experiment 2
Continuously at 2 °C	2.17	2.83
Continuously at 10 °C	0.21	0.48
16 h at 2 °C then 8 h at 10 °C	–	0.68
8 h at 2 °C then 16 h at 10 °C	0.49	–

Diseases and disorders

There are many storage diseases and disorders. These are dealt with in detail in Snowdon (1991). World-wide potato diseases were reviewed by Jeger *et al.* (1996) including those caused by *Verticillium dahliae*, *Rhizoctonia solani*, *Spongospora subterranea* and a group normally considered as tuber borne, including *Colletotrichum coccodes*, *Helminthosporium solani* and *Fusarium* spp. It was suggested that the long-term persistence of survival structures, difficulties in reducing inoculum and lack of good sources of resistance generally hinder the control of soil-borne fungal pathogens. Postharvest fungicide treatment of seed or ware potatoes does not entirely alleviate storage disease problems. The various tuber diseases and disorders that can occur during storage may have their origin during production or may be due to the environmental conditions or infections that occur during storage. Their source may be infection with micro-organisms, particularly fungi and bacteria and occasionally viruses, but the symptoms may be caused by the tubers' reaction to infection, nutritional deficiency or imbalance or environmental conditions.

The following list of diseases and disorders is arranged alphabetically and names may be taken from the symptoms which are produced or the source of the diseases or disorder. In some cases infection with the same micro-organism may result in different symptoms and therefore different names for the disease and even different control measures.

Bacterial hard rot

Infection occurs through wounds or lenticels on the tuber surface. The bacteria (*Erwinia carotovora* subspecies *atroseptica*) needs moisture for infection so it is common where tubers are wet at harvest, or where they are washed before storage or where water

condenses on tuber surfaces because of inadequate temperature and or humidity control during storage. If moist conditions prevail the disease is bacterial soft rot but if tubers dry out after infection the lesions are discrete firm, brownish black and sunken. Weber (1988) showed that the defence reaction of potatoes to infection during the curing period was inhibited by temperatures of less than 10 °C, reduced O₂ levels of less than 5% and CO₂ levels of over 20%. Control methods are the same as those described for bacterial soft rot.

Bacterial soft rots

Soft rot disease caused great losses in tubers, especially during storage particularly in less developed countries (El-Sayed 1996). Bacterial soft rot is caused by infection with *Erwinia carotovora* subspecies *atroseptica*. Infection is mainly from the soil through wounds or lenticels on the tuber surface. Infection is facilitated where there is a film of water on the tuber surface. Wyatt and Lund (1981) showed that the time required for infection varied with temperature. At 22 °C infection can occur through lenticels in 2 1/2 h but at 10 °C it took 6 1/2 h. The bacteria feed on living cells and are in two general forms depending on the source of infection. If infection was through a lenticel the initial infection is circular with soft creamy coloured cells which eventually turn black. If infection is through damaged tissue the soft creamy coloured cells have a less regular outline. The bacteria multiply rapidly under optimum conditions and the whole tuber can rot very quickly. If the conditions dry out shortly after infection the spread of the disease is restricted resulting in bacterial hard rot disease. With the rapid growth of the disease considerable heat is produced and where the disease develops in storage this heat output can be detected by temperature monitoring probes and the store unloaded to restrict the damage.

It has been shown that cultivars differ in their susceptibility to soft rot. Nineteen of the most popular Polish potato cultivars were screened for resistance to bacterial soft rot caused by *E. carotovora* subsp. *carotovora*. Susceptibility of tubers was assessed by two methods: direct injection of the bacterial suspension into tuber tissue and a clay-inoculation method. The cultivars were divided into three groups: tolerant, relatively susceptible and susceptible. The cultivars Elida, Bila and Vistula were the most susceptible

and Ekra and Mila were the most resistant cultivars. Some of the cultivars such as Oda had resistant peel and susceptible tissue and therefore should be stored in a healthy and undamaged state to prevent bacterial penetration and development of soft rot (Zolobowska *et al.* 1998). Tubers of the cultivar Driver developed in New Zealand were shown to be moderately resistant to and bacterial soft rot (Anderson *et al.* 1997).

Storage temperature can affect the development of soft rot. In India tubers were stored in a country store at an average temperature of 26 °C and 63% r.h. or in cold storage at an average temperature of 4 °C and 88% r.h. Considerable levels of soft rot were detected in the country store but none in tubers in cold storage (Somani and Shekhawat 1988).

Fertilizer application to the growing crop has been shown to affect soft rot levels. In India the application of high rates of N (300 kg ha⁻¹) increases soft-rot incidence but this could be minimized by applying liquid fertilizer N. The use of ammonium chloride led to more soft rot and its use in potato cultivation was discouraged (Somani and Shekhawat 1988). In studies on a sandy soil in Florida, United States, on the applications of Ca as CaSO₄ it was concluded that the efficacy of Ca applications to potatoes grown in low Ca soils for enhancement of tuber resistance to *E. carotovora* subsp. *carotovora* may be limited by environmental or cultivar factors that are incompletely understood (Bartz *et al.* 1992).

Soft rots have been associated with *Salmonella*. Samples of fresh fruits and vegetables, collected in supermarkets in New Jersey, USA, during 1992–1995, showed that *Salmonella* contamination was potentially present in at least 18–20% of soft rotted samples and in 9–10% of healthy samples. Fresh potato, carrot and pepper discs co-inoculated with *E. carotovora* and *Salmonella typhimurium* and incubated for up to 72 h at room temperature, contained approximately 10 times the concentration of *S. typhimurium* as did discs inoculated with *Salmonella* alone (Wells and Butterfield 1999). In *in vitro* studies on potato slices, *E. herbicola* Eh252 inhibited the development of soft rot when the slices were treated with a suspension of *E. herbicola* Eh252 before being inoculation with *E. carotovora* subsp. *atroseptica*. The degree of inhibition depended on the amount of Eh252 applied (Vanneste *et al.* 1994). Resistance to bacterial soft rot disease of potato tubers was shown to be induced by acetyl salicylic

acid (aspirin) (El-Sayed 1996) but it would appear unlikely that this treatment would be permitted to be used commercially.

A study was conducted by Ranganna *et al.* (1998) to determine whether spoilage of potato tubers during storage could be controlled by a hot water treatment without affecting quality. The study demonstrated that Superior tubers inoculated with *E. carotovora* subsp. *carotovora* and *Fusarium solani* then immersed in water at 57.5 °C for 20–30 min did not develop soft rot during 12 weeks storage at either 8 or 18 °C with no evidence of damage due to the thermal treatment.

In the Ukraine Ivashchenko *et al.* (1997) investigated the phenolic compound contents of susceptible cultivars (Nezabudka and Kaskad Polis'kii), intermediately resistant cultivars (Lugovs'ka and Zov) and more resistant cultivars (Svitanok kiivs'kii and Gatchins'ka). The tubers were either healthy or inoculated with *E. carotovora* subsp. *carotovora* and *E. carotovora* subsp. *atroseptica*. The results showed that phenolic compounds increased potato resistance to storage diseases. Differences in phenolic compound contents were found between resistant and susceptible and between healthy and inoculated potatoes. Healthy potatoes of the resistant cultivars showed phenolic compound contents 22.8% higher than the susceptible ones. The contents of the phenolic compounds in the resistant cultivars increased by 3–6% and those in susceptible by 56–58%. In artificial inoculations, the contents increased by 43% in the resistant and by 18% in the susceptible cultivars over the whole storage period. In inoculated potatoes of resistant cultivars, the contents of the phenolic compounds were significantly higher than those in the susceptible ones at all stages of the storage period. Pre-sowing applications of stable bleaching powder and streptomycin were effective for preventing soft rot (caused by *E. carotovora*), sprouting and weight loss of potato tubers (grown in Haryana, India) in cold storage (Karwasra and Parashar, 1998). The effect of ozone on *E. carotovora* subsp. *atroseptica* was limited. It was concluded that careful washing of seed potatoes does not cause rot provided the tubers are dried thoroughly. The addition of a disinfectant at the end of washing further reduced tuber rot (Ridder 1996). Compounds such as sodium metabisulphate, propyl paraben, alum, potassium sorbate, calcium propionate and copper sulphate pentahydrate showed

that they inhibited *E. carotovora* ssp. *atroseptica* and *E. carotovora* ssp. *carotovora* (Mills *et al.* 2006).

Black dot

Black dot is a fungal disease of tubers caused by infections with *Colletotrichum coccodes*. It is more prevalent during wet growing periods. Symptoms develop on the tuber surface as minute black dots that progressively get larger and are particularly obvious on coloured tubers especially after being washed. Symptoms can be similar to silver scurf. The fungus can persist in the soil or on weeds or soil organic matter or can be introduced on infected tubers.

Black dot is usually considered as a minor disease of potato in France, but the recent rise in sales of washed tubers for the fresh market makes tuber-blemishing diseases of increasing concern to growers. Recent surveys showed that the pathogen is widespread in French potato-producing areas and that most cultivars are susceptible to the disease (Guerin *et al.* 1997).

Several potato cultivars were inoculated with various *C. coccodes* isolates by Andrivon *et al.* (1998). Symptoms developed first on underground organs (starting 2 weeks after inoculation on roots and later on stolons and tubers) of inoculated plants; stem infections developed only after 7–10 weeks, depending on the cultivar. Significant isolate by cultivar interactions were detected from the analysis of root symptoms after inoculation of three cultivars (Bintje, Spunta and Desiree) with five *C. coccodes* isolates. Such an interaction was also detected for stolon/tuber symptoms at the latest scoring date (98 days after inoculation) but not at earlier dates (58, 70 and 84 days after inoculation). These results suggested that protocols based on root colonization might be used for investigating cultivar response to black dot and pathogenicity of *C. coccodes* isolates and that some specificity exists in the reaction of potato genotypes to this pathogenic fungus.

In France two cultivars (Charlotte and Samba) showed symptoms of the disease on the stems and leaves, and the presence of *C. coccodes* sclerotia was confirmed. However, after harvesting, the tubers showed none of the normal black dot symptoms and the yield was normal. It was suggested that climate can upset the life cycle of the potato, by providing favourable conditions for the development of the fungi, or that the re-use of affected plots

can contribute to the development of the disease (Dehorter 1998).

Crop rotation and planting uninfected seed tubers help to reduce the disease. Where crop rotation is used it is essential that other solanaceous crops are not part of the rotation and solanaceous weeds are controlled (Denner *et al.* 1998). Soil in a potato field naturally infected with black dot in Pretoria, South Africa, was fumigated with methyl bromide at 126 g m⁻² or was left non-fumigated. Seed tubers of potato cultivar BP1 which were uninfected, lightly infected (1–25% surface affected) or severely infected (26–100% surface affected) with *C. coccodes* and dusted with prochloraz manganese chloride (as Octave 2.5% DP) at 750 g per 100 kg seed were planted in fumigated and non-fumigated soils. When harvested, the incidence of black dot on the progeny of infected seed planted in non-fumigated soil was twice that of progeny in fumigated soil, with progeny of uninfected seed having 68.5 times higher disease incidence in non-fumigated soil. Black dot on progeny tubers was reduced by pre-treatment of seed with prochloraz in fumigated soil only. It is concluded that in black dot infected fields, planting disease-free seed or treating seed with fungicides would not decrease disease on progeny tubers.

Seed tubers of cultivars Desiree and Pentland Crown with different severities of black dot were planted in 1988 and 1989 at Rothamsted, UK, by Read and Hide (1995) in fields in four- or seven-course rotations, respectively. Tubers treated with prochloraz (1988) or imazalil (1989) were planted in some plots and in others *C. coccodes* inoculum was added to the soil at planting. In further experiments at Mepal, Cambridgeshire, UK, in 1989 and 1990 and at Rothamsted in 1990 on sites where potatoes had not been grown for more than 15 years, large amounts of inoculum were added to the soil around disease-free seed tubers of two (1989) or three (1990) cultivars at planting. In all experiments plants were sampled during the season and the effects of treatments on disease development, growth and yield were recorded. Disease on roots, stem bases and tubers was found early in the season and was more severe on Desiree than on Pentland Crown plants from fields in four- or seven-course rotations. Severity increased throughout the season and with increasing amounts of disease on the seed tubers, especially with Desiree. Disease was also found on plants from disease-free

tubers and was more severe in 1988 than 1989. At harvest, black dot on tubers was significantly more severe from severely affected than from disease-free seed and was most severe where inoculum, especially large amounts, had been added at planting. Fungicide treatment decreased disease early in the season but had no effect on tuber infection at harvest. In 1989 the weight loss of seed tubers during sprouting increased with increasing amounts of black dot, but the disease had little effect on plant size through the season. At harvest the yield of ware tubers (>50 mm) decreased with severe disease but total tuber yields were not significantly affected. At harvest in 1988 severely affected seed yielded significantly less than healthy seed. Plants grown from mini-tubers were free from disease on sites where potatoes had not been grown for at least 15 years. Inoculum applied at planting caused severe disease on all cultivars in both years, whereas disease was slight on non-inoculated plants. Inoculated plants senesced early at Mepal in 1990, but there were no significant differences in total tuber yield in any experiment. Yields of ware tubers (>50 mm) were sometimes decreased and the total tuber number per plant is increased.

Helminthosporium is a slower growing organism that spreads via spores (Stevenson *et al.* 2001). Potato seed tubers infected with *Helminthosporium solani* and *C. coccodes* were treated with prochloraz (as Omega 450 g a.i. per litre EC) and/or prochloraz manganese chloride (as Octave 25 g per kg DP) and were planted in two separate fields not previously cultivated with potatoes. Dipping seed 28 days prior to planting in 2, 4 or 6 g a.i. per litre Omega, and dusting with 500 or 750 g Octave per 100 kg seed, significantly reduced silver scurf and black dot incidences on progeny tubers. In one field, the higher concentrations of prochloraz or prochloraz manganese chloride gave slightly better control than the lower prochloraz concentrations. At the second site, postharvest application of 4 g a.i. per litre Omega or 750 g Octave per 100 kg seed limited development of both diseases on progeny tubers, with slightly better control when an additional prochloraz manganese chloride was applied 14 days before planting. None of the prochloraz treatments adversely affected plant stand or tuber yield (Denner *et al.* 1997).

There was some evidence of control of black dot by pencycuron plus tolylfluanid. From observations on plant growth and yield, the co-formulation appears

to be very safe to the crop (Wainwright *et al.* 1996). The ability of *T. viride* and *T. harzianum* to control black dot disease on two cultivars (Aula and Draga) of potatoes was determined. Addition of *T. viride* to infected soil indicated that this isolate was able to reduce disease on cultivar Draga (Okhovat *et al.* 1994). Most fungicides applied to the seed tubers for controlling other seedborne diseases such as silver scurf (*Helminthosporium solani*) or black scurf (*Rhizoctonia solani*) are not effective against the black dot pathogen (Guerin *et al.* 1997). When applied as a pre-planting seed tuber treatment, fenpiclonil controlled black dot to a commercially acceptable level (Leadbeater and Kirk 1992).

Black eye

The development of black eye [caused by *Fusarium solani* (Fs) (*F. solani* f.sp. *eumartii*)] was evaluated on stored infected potato tubers from plants of cultivars Achat and Baronesa and on tubers inoculated with 20 isolates of *F. solani*, comprising three experiments. In the first and second assays, tubers without (latent infection) and with (apparent infection) symptoms were stored at conventional cold temperature (4 °C) or at room temperature (27 ± 2 °C). Symptoms were assessed on a 0–5 scale (0 = tuber showing no apparent symptoms and 5 = 50–100% of rotted tuber). In addition, after evaluation, infected tubers were planted in pots in a greenhouse and disease severity was rated on tubers after harvesting. The storage of infected tubers at 4° did not stop disease progress for both tuber groups. Tubers with apparent infection rotted faster than those with latent infection. Symptoms of black eye were reproduced on plants originating from infected tubers regardless of infection level. Plants originating from tubers with apparent infection showed characteristic symptoms of the disease earlier than those from tubers with latent infection. In the third assay, 20 isolates of Fs were inoculated in tubers of cultivars Achat and Baronesa and stored at 10 ± 1 °C or at room temperature (27 ± 2 °C). Tubers kept at room temperature rotted faster; however, they showed infection corresponding to level 1 of the disease (Lima and Lopes 1998).

Black pit (*Alternaria* rot)

Several species of *Alternaria* infect tubers causing them to rot. The one causing black pit is *A. alternata*.

Black scurf

Black scurf is caused by infections with the fungus *Rhizoctonia solani*. Tuber infections result in brown or black bodies on the surface giving them an unsightly appearance. Infection rarely results in rotting. *Rhizoctonia* does not spread from tuber to tuber in storage but the lesions (sclerotia) are formed on the tubers late in the season, following vine death. Late harvests can also increase levels of *Rhizoctonia* black scurf on the tuber surface (Stevenson *et al.* 2001). Lakra (1995) showed that an increase in irrigation stimulated black scurf disease development. Highest soil moisture (1 : CPE = 40 : 20 mm) resulted in 64.8% necrotic stems, 28.1% post-emergence wilt and 100% scurf in harvested potato tubers and 58.6% loss in tuber yield when a crop was raised with diseased tubers. Disease severity was positively correlated with the amount of inoculum and soil moisture content in the field. The incidence of black scurf was generally not affected by K rate; however, there was a tendency in some site years for a higher disease incidence when KCl was used instead of K_2SO_4 (Panique *et al.* 1997).

Treatment of seed potatoes by Welsh and O'Callaghan (1996) with fenpiclonil (50 g tonne⁻¹) gave similar levels of control of *R. solani* as tolclofos-methyl and benomyl at crop establishment and harvest. Treatments significantly reduced the level of infection compared with the untreated control. There was no difference in disease control where fenpiclonil was used either as a dust or liquid formulation. Benomyl use is not permitted in many countries. Field experiments were conducted by Lootsma and Scholte (1996) to assess the effects of chemical soil disinfection at planting and methods of harvesting potatoes on stem infection with *R. solani* in the subsequent year. In the first year of the experiments, seven methods, including one with soil disinfection at planting, were applied in August. In the following year, *R. solani* stem and stolon infection (disease severity) on potato plants were assessed in June. Soil treatment at planting with pencycuron resulted in the lowest disease severity in the following year. Compared with chemical haulm killing and haulm pulling, immature crop harvesting also resulted in a lower disease severity, but only when black scurf was scarce on tubers at harvest in the preceding year. Read and Hide 1995, however, showed that soil treatment with 1,3-dichloropropene,

aldicarb or ethoprophos had no effect on black dot, but *R. solani* tuber infection and black scurf were increased. In this combined formulation, the performance of pencycuron against black scurf was not affected and 97% control was observed (Wainwright *et al.* 1996). When applied as a pre-planting seed tuber treatment, fenpiclonil controlled black scurf and stem canker to a commercially acceptable level (Leadbeater and Kirk 1992).

Blackheart (black heart)

Exposure of potatoes to low O₂, especially at high temperatures of around 25 °C, can result in necrotic cells being produced in the centre of the tuber. This is called Blackheart and the cells contain melanin in both the protoplasm and cell walls. Chlorogenic acid and tyrosine tend to accumulate in affected areas and the state and distribution of lipid changes (Reeve 1968). Lipton (1967) found that in storage 15 or 20 °C Blackheart developed in tubers held in 1 or 0.5% O₂. Voss (2002) reported that Blackheart was induced at greater than 30 °C, which also increased their respiration rate.

Blackspot (black spot)

Tubers exposed to mechanical damage can develop dark patches under the intact skin, sometimes known as blackspot or blue spot. It develops as a result of bruising due to impact or pressure during harvesting, handling and storage and is a common and important defect which affects the marketability of potatoes. Cobb (1998) described the sequence of events which occur after impact damage to tubers initially causing collapse of the intracellular compartmentation and then the synthesis of melanin as a dark amorphous layer. It is therefore observed as a bluish grey spot which develops in the vascular region within a few millimetres of the skin. Cobb (1998) indicated that they are usually limited to 5–10 mm in diameter and located some 2 mm below the periderm and defined it as 'sub-surface damage to the tuber tissue which subsequently causes blue/grey to black discolouration of the flesh'. Stevens and Davelaar (1996) showed that blackspot formation most probably takes place in disintegrated cells. They also showed in the cultivars studied that the pigments consisted of protein and a relatively small amount of covalently bound constituents. These polymeric structures absorbed light throughout the visible spectrum without any maximum. They did not contain eumelanin. Quinic acid

was detectable in hydrolysates of the pigments from Bildstar, but not in those of Lady Rosetta, which indicated that chlorogenic acid may take part in blackspot formation, but is not essential for the discolouration. The results support the hypothesis that blackspot pigments are products of non-regulated reactions between nucleophilic amino acid residues in proteins, and quinones, which are derived from endogenous substrates of PPO.

Potatoes cultivar Pentland Dell tubers were impacted with a falling bolt at harvesting at ADAS Arthur Rickwood, Cambridgeshire, UK, or at 12 weekly intervals thereafter through storage. Impacted and control tubers were incubated at 22°C for 48 h before sampling for ultrastructural analysis. Tubers impacted at harvest developed microscopic shatter compared with stored tubers which formed blackspot bruise. Microscopic shatter was characterized as a disrupted tonoplast showing vesicularization, increased numbers of mitochondria and nuclear invaginations. In severe cases, tissue damage resulted in cavities forming within the cells. Conversely, blackspot formation typically appeared as melanin formation surrounding the starch grains and adjacent to the cell wall (Edgell and Cobb 1998). It has been shown that there is a difference in susceptibility to blackspot between cultivars (Brierley *et al.* 1998). Love *et al.* (1993) evaluated clones for blackspot bruise potential and selected eight with significantly better blackspot bruise resistance. The susceptibility of 40 potato cultivars to discolouration (raw pulp discolouration, cooking darkening and black spot) was studied by (Hornburg and Wirsing 1995). Tubers were stored at room temperature for 5–8 days and a black spot index was calculated from the percentage of tubers showing slight, moderate or severe discolouration of a cut surface. Cultivars were assessed in December and April. There were clear differences in black spot susceptibility between cultivars and years. The ranking of cultivars differed in different years; environmentally stable and environmentally labile cultivars were distinguished. Black spot was generally more severe in spring than in autumn. The ranking of most cultivars remained the same, but some showed above average increases in black spot index during storage. Eight early maturing, 21 mid-early and 7 mid-late to late ware cultivars were screened by Altenburg (1993) for susceptibility to black spot. Cultivars with high

tuber starch contents tended to show the highest degree of black spot occurrence. Among the early cultivars, Miriam tubers were of high quality (no discolouring), whereas Rikea and Ute tubers showed heavy discolouration. Among the mid-early cultivars, Solara, Quarta and Agria showed the fewest black spots (2–3% of the tuber surface), whereas in both Adretta and Ponto 50% of the tuber surface was discoloured. All mid-late and late cultivars were highly susceptible to black spot, particularly Indira and Producent. McRae (1985) reported that tubers, which had lost moisture either during production in the field or during storage, became more susceptible to blackspot. It was therefore recommended that irrigation be provided where necessary and store humidity should be maintained at a high level. However, water status was shown by Effmert (1988) to have little influence on black spot, induced by mechanical damage, during storage initially at 4–6°C and in spring at ambient temperature of 18 or 20°C. Hornburg and Wirsing (1995) also found that the effects of irrigation were inconsistent. Changes in periderm water vapour permeability and some changes in cellular integrity were monitored by Lulai *et al.* (1996) in pressure-bruised areas and non-pressure-bruised areas of tubers of the cultivar Monona. These were stored for 8 months in a commercial storage bin filled to a pile depth of 4–4½ m. Pressure-bruised areas revealed elevated water vapour loss, which is conducive to black spot formation, even though there were no apparent breaks in the periderm of pressure-bruised areas. Pressure-bruised areas did not readily wound heal because of continuing increased water vapour loss. The tough, rigid cells of the suberized phellem were damaged or completely flattened by this form of stress. A layer of what appeared to be crushed cells was often detected beneath the pressure-bruised, but partially intact, phellem. In field trials, black spot development during subsequent storage was most severe with no fertilizer or only mineral N, P and Ca, with or without K and least severe with P, K and Ca. Adequate K application, use of farmyard manure and limited N application were important in avoiding black spot. In the short-term trials, increasing N rates were not associated with increased black spot (Hornburg and Wirsing 1995). Cobb (1998) showed that the activity of the enzyme PPO was reduced in potatoes grown with potassium fertilizer. Melanin

is formed in bruised tissue by the action of PPO on tyrosine.

Mathew and Hyde (1997) focused on the effects of temperature and cushioning on bruising (impact damage) thresholds. Russet Burbank tubers at 10, 15.5 and 21 °C were dropped from 10 heights onto a steel surface and onto cushioned surfaces of thickness 6.3 and 13 mm. Tubers at the lowest temperature were the most susceptible to damage. Cushioning the impact surface reduced the amount of bruising in all cases. As drop height increased, bruise type shifted from black spot to shatter bruise and cracking, implying a continuum of damage type that is dependent at least in part on approach velocity. Tubers which had been exposed to ethylene (15 µl L⁻¹) prior to testing for susceptibility to bruising were found to be more resistant, but no reason could be found for this effect (Brierley *et al.* 1998).

Blight (early)

Infections with *Alternaria solani* can cause early blight on the haulm, but the fungus can also infect the tuber causing storage rots.

Blight (late)

Potato late blight is caused by infection with the fungus *Phytophthora infestans*. It can be caused serious preharvest and postharvest diseases, resulting in significant rot of potato tubers when plants become infected in the field (Taylor *et al.* 2004). Blight devastated the potato crop in Ireland in the middle of the 19th century resulting in famine. The relative aggressiveness of *P. infestans* clones in potato tubers was compared in three trials using 7–24 isolates of 2–4 clones. A visible rot developed slowly at 13 °C with isolates of the US-1 genotype, the only significant clone found in North America prior to 1979, but substantially faster with most isolates of the newer clonal genotypes US-6, US-7 and US-8. Certain US-7 isolates were similar to US-1. US-6 isolates also had a broad range of aggressiveness (Lambert and Currier 1997).

Late blight is the most important disease of potato in the hills of Nepal and misuse of fungicides is common because of a lack of understanding of the disease by farmers. Application of mancozeb or copper oxychloride dependent on weather conditions effectively managed the disease, was economical and increased tuber yield by 50% over previous farmer practices

(Dhital *et al.* 1996). Field trials on reduced chemical inputs for potato production carried out in Finland by Varis *et al.* (1996). They included the cultivars Bintje, Record and Matilda, which differed in their late blight resistance. They found that storage losses, caused mainly by tuber blight, were particularly high in organically grown potatoes of all three cultivars.

Pink rot

Phytophthora erythroseptica Pethybr. can be a serious preharvest and postharvest diseases, causing significant rot of potato tubers when plants become infected in the field (Taylor *et al.* 2004). Secor *et al.* (2004) treated freshly harvested tubers with Phostrol® (sodium, potassium and ammonium phosphates) at 12.8 ounces per tonnes then placed them in boxes and stored them at 10 °C. Total pink rot infection was 62.7% for tubers that were not treated and only 2.0% for those that had been treated with Phostrol®. Olsen *et al.* (2004) treated freshly harvested tubers with Phostrol® at 12.8 ounces per tonnes then placed them in boxes and stored them at 12.8 °C for 14 days and then reduced the temperature by 0.5 °F per day until it reached 8.9 °C and 95% r.h. The total storage time was 77 days and no disease was detected on the tubers that had been treated with Phostrol® while over 60% of none treated tubers developed pink rot and over 90% developed late blight.

Brown rot

Brown rot disease caused by *Pseudomonas (Ralstonia) solanacearum*. The *P. solanacearum* biovar 2A has occurred in southern Europe from 1940 and was observed in Sweden in 1972. More recently, an isolated outbreak recorded in England in 1992 was followed by reports of other sporadic outbreaks in other parts of northern Europe (Stead *et al.* 1996). Since 1992 an increased number of outbreaks of brown rot, caused by race 3, biovar 2, have been reported in several European countries, including Belgium, France and the Netherlands. The largest outbreak occurred in the Netherlands in 1995, mainly through a heavily infected seed tuber line (Janse 1996, Durand 1996). To avoid introduction of this dangerous quarantine disease into other countries of the European Union, the phytosanitary regulations on *P. solanacearum* were implemented by the European Commission in November 1995 (Van Schingen 1996). In 1996 severe quarantine measures against brown rot were effective,

and no new cases were reported in France during that year. However, the causal agent still occurs in Europe and attention must not be relaxed (Gilet 1996). The tests carried out on potato imports into France at the Service Regional de la Protection des Vegetaux Nord-Pas de Calais laboratory: results up to March 5, 1996, showed that none of the potato lots examined from the Netherlands had been contaminated *P. solanacearum* (Decoin 1996). In the most affected countries, the bacterium occurred in surface water and in the weed *Solanum dulcamara* growing along waterways. In some countries, tomato was also infected (Janse 1996). Evidence from several countries suggests that the pathogen can successfully over-winter from which it can spread to crops when associated water is used for irrigation (Stead *et al.* 1996).

Current control measures, governed by national and European Union plant health legislation (Stead *et al.* 1996), rely on accurate detection and reporting of brown rot outbreaks and distribution of the pathogen, prevention of importation of potatoes from known infected areas and restrictions on use of infested land and irrigation water for potato production. Janse (1996) suggested the following control strategies:

- responsibility for prevention and control is for the country where the disease occurs;
- countries where the disease occurs should report outbreaks as soon as possible;
- early and sure detection and diagnosis of the pathogen are the core of the system;
- adequate prevention and control measures should be taken after an outbreak;
- production of healthy seed tubers should be guaranteed and surveys and (laboratory) checks for (latent) infections performed;
- education of scientific personnel and the public (farmers, traders, advisory service etc.) is essential. It is suggested that hygienic measures and avoidance of surface water for irrigation will be the key factors in successful control of the disease.

Dry conditions decreased the survival period of the bacteria. Survival on wood, metal and rubber was also tested. The maximum survival period on wood was very short (4 days) compared with metal (14 days) and rubber (55–87 days). The disinfection of surface water after a 15-min application of maneb,

hydrogen peroxide, hydrogen peroxide + acetic acid and calcium hypochlorite was measured in the laboratory. Maneb and hydrogen peroxide were not effective in disinfecting contaminated water (Wenneker *et al.* 1998).

Charcoal rot

Charcoal rot is caused by infection with the fungus *Macrophomina phaseolina*. Extensive surveys in 23 locations in India showed that the incidence of charcoal rot was very high in late harvested crops when the temperature rose above 30 °C and slight negligence of late harvest resulted in heavy losses (Somani and Chauhan 1996).

Common scab

Caused by infection with species of the bacterium *Streptomyces* especially *S. scabies*. Of 169 strains of the common scab pathogen isolated from diseased potatoes in Siberia, Russia, *S. globisporus* was the most frequent, followed by *S. chromogenes*, *S. griseobrunneus* and *S. violaceus* (Everstova and Chumakov 1991). It inhabits the soil either as spores or as strands within crop debris. It can be spread by water or wind or on infected seed potatoes. Infection is through wounds or immature lenticels. Cork is formed in the areas of infection as a natural defence mechanism and it is this cork formation which gives the typical scabby appearance of infected tubers. Dry soil conditions during the initial period of tuber development and a temperature of 19–24 °C favour the disease. The effect of dry conditions could be because the numbers of potentially antagonistic bacteria in the soil would be reduced (Adams and Lapwood 1978). During storage, common scab infection contributed to the developments of dry and wet rots (Everstova and Chumakov 1991).

The disease can be controlled by crop rotation. Crop rotation with cabbage was shown to decrease common scab infection (Everstova and Chumakov 1991). Irrigation for several weeks after the time from emergence, especially where there is a high water deficit, was also shown to reduce infections (Adams and Lapwood 1978).

Compression bruising

Compression damage or crushing is where the downward force on the crop is above a threshold level resulting in bruising. This often results in the physiological disorder called blackspot. This damage may

also be a function of time, especially where the pressure is close to the threshold value. It may be as a result of overfilling boxes and then stacking the boxes so that the crop in the lower boxes supports the weight. It is also commonly found in the lower layers of potatoes in bulk stores. There are differences between cultivars in their susceptibility to compression damage. It may also be related to their moisture content, the higher their moisture content the more they are susceptible, which, in turn, may be related to preharvest cultural effects. To overcome the problem it may be necessary to redesign boxes or ensure that they are not over filled. In crops which are bulk stored a certain level of compression bruising may be accepted to maximize the capacity of the stores for economic reasons.

Carbon dioxide toxicity

The harmful effects of increased CO₂ concentrations on potatoes during storage were described by Smith (1977). They referred to the increased susceptibility of potato tubers to internal black spot and bacterial soft rot. Schouten (1992) also reported the same findings. Potatoes stored at 10–20 °C breakdown and rot in 20% CO₂, often in 15%, but will survive 10% CO₂ (Kidd 1919, Burton 1958). Reust *et al.* (1984) found that in the presence of 2% O₂, increasing CO₂ concentrations, over the range 1–12%, led to increasing levels of storage rots. In another experiment Reust *et al.* (1984) found that no rotting was recorded after 118 days of storage at 8 °C in a combination of 6% CO₂ with 15% O₂. Workman and Twomey (1970) showed that increasing CO₂ concentration over the range 4–12% resulted in either complete tuber breakdown during storage or an increased decay of cut seed by an undefined *Fusarium* sp. The toxicity of CO₂ was increased at lower storage temperatures (0–5 °C) and lower O₂ concentrations (at 1% and below). Using 100% N₂ (anaerobic conditions), Sherman and Ewing (1983) showed that at 1 °C all cultivars tested developed black heart when tubers were returned to air, while in storage at 10 °C, they developed soft rot. Storage in 1% CO₂ combined with 0.5–1% O₂ Schouten (1992) observed some rotting at 6 and 10 °C, while at 2 °C rotting was almost completely absent.

Dry rot

Several genera and species of fungi have been associated with dry rot. In Holland (Turkensteen and

Mulder 1996) the fungal pathogens causing dry rots were divided into three groups: those causing early infection via the leaves (*Phytophthora infestans* and *Alternaria solani*), see sections on Blight, those causing early infection via the soil [*Phoma* (*exigua* var.) *foveata*, *Fusarium sulphureum* (*Gibberella cyanogena*) and other *Fusarium* spp *Armillaria mellea*, *Rosellinia necatrix* and nematodes belonging to the genus *Ditylenchus*] and those causing infections later in the storage period (*F. oxysporum*, *F. solani* and *P. exigua*). *Fusarium* dry rot is one of the most important postharvest diseases of potato, with losses typically ranging from 6 to 25% and reaching 60% in some situations (Stevenson *et al.* 2001). The most frequently isolated species from dry rot infected tubers in Bosnia and Herzegovina by Aprasad *et al.* (1997) were *Fusarium solani* var. *coeruleum*, *F. sulphureum* (*Gibberella cyanogena*), *F. graminearum* (*G. zeae*) and *F. lateritium* (*G. baccata*). The most common species was *F. solani* var. *coeruleum*, while the highest pathogenicity was detected in *G. zeae*. The most susceptible variety was Ranka, followed by Desire, while the hybrid S-79-1K/20 was the most resistant (Tamburic Ilinic 1996). The majority of isolates of *F. avenaceum* (*G. avenacea*) caused dry rot on potato tubers; many were as pathogenic as *F. coeruleum* (*F. solani* var. *coeruleum*). Pathogenicity of *G. avenacea* was not related to the plant species from which the isolates originated. From a total of 120 tubers in Poland, 1232 fungal isolations were made by Kurzawinska (1997) which were identified as 24 species and 13 genera. In the autumn *Alternaria alternata* prevailed, constituting 30.6% of all the isolates followed by *Rhizoctonia solani* 13.1%, *Fusarium sulphureum* (*Gibberella cyanogena*) 12.2%, *Colletotrichum coccodes* 9.9%, *F. coeruleum* (*F. solani* var. *coeruleum*) and *F. culmorum* 7.7% each. In the spring *G. cyanogena* 29.7%, *F. solani* var. *coeruleum* 18.2%, *F. culmorum* 7.5% and *A. alternata* 6.7% were the prevalent species. Fungi were isolated from wounds or pre-existing lesions on randomly collected samples of seed, table-stock and processing tubers by Hanson *et al.* (1996). Of 154 samples, 99 yielded 1 or more *Fusarium* isolates, 98% of which were pathogenic on potato tubers. The most frequently recovered pathogenic species were *F. sambucinum* (*G. pulicaris*), *F. solani* and *F. oxysporum*, but pathogenic isolates of *F. acuminatum* (*G. acuminata*), *F. avenaceum* (*G. avenacea*), *F. crookwellense*, *F. culmorum* and *F. equiseti* were

also isolated. During 1989–1992, the fungal species occurring in dry rot of potato (cultivar Mila) tubers under natural conditions was investigated. Samples of tubers were harvested at the Agricultural Experimental Station Mydlniki of the University of Agriculture in Krakow, Poland, and analyses were conducted in the autumn (1 month after harvest) and in the spring after 7 months of storage. From a total of 120 tubers, 1232 fungal isolations were made which were identified as 24 species and 13 genera. In the autumn *Alternaria alternata* prevailed, constituting 30.6% of all the isolates followed by *Rhizoctonia solani* 13.1%, *Fusarium sulphureum* (*Gibberella cyanogena*) 12.2%, *Colletotrichum coccodes* 9.9%, *F. coeruleum* (*F. solani* var. *coeruleum*) and *F. culmorum* 7.7% each. In the spring *G. cyanogena* 29.7%, *F. solani* var. *coeruleum* 18.2%, *F. culmorum* 7.5% and *A. alternata* 6.7% were the prevalent species.

Symptoms vary between the species of fungus causing the disease, time of infection and storage environment. Tuber infection is associated with mechanical damage or lenticels where lesions are formed. The margins of the lesion may be either very clearly defined or quite diffuse. As the fungus develops lesions coalesce and the infected tissue dries out and can become wrinkled (Kurzawinska 1997). There are cultivar differences in susceptibility to dry rot. Tubers of the cultivar Cara were more susceptible than those of cultivars Romano or Maris Piper (Aprasad *et al.* 1997). In a study to determine resistance to dry rot of three cultivars Tamburic Ilincic (1996) found that the most susceptible was Ranka, followed by Desire, while the hybrid S-79-1K/20 was the most resistant. Storage temperature had little effect. At 5–15 °C there was no effect on lesion depth, but lesions tended to be slightly wider at the lowest temperature (Aprasad *et al.* 1997).

Fusarium inoculum is initially found in contaminated soil or in tubers infected with *Fusarium* dry rot spores. *Fusarium* dry rot requires wounds or entry points to infect tubers. Once infection has taken place, the disease continues to develop within infected individual tubers for the duration of the storage period. Slightly darkened, shallow lesions become apparent within 1 month of infection. As the disease spreads, the infected tissues become sunken and somewhat wrinkled, with concentric rings of discoloured tissue radiating from the initial infection point. Rotted tissues are dry, with cavities lined with

mycelium and spores. Tubers may become completely shrivelled after a period of time as the rot advances and the damaged tissues dry. *Fusarium* does not spread between tubers in storage (Stevenson *et al.* 2001).

Low temperatures throughout the storage period will slow but not halt development of dry rot (Stevenson *et al.* 2001). Ultraviolet radiation completely suppressed the development of dry rot in tubers stored at 8 °C for 3 months. Disease suppression increased as the ultraviolet dose increased but decreased with increasing pre-treatment incubation length. Dry rot was completely suppressed ultraviolet dose of 12.5 kJ m⁻². The ultraviolet doses tested had no effect on the sprouting, texture, firmness or colour of the potatoes (Ranganna *et al.* 1997). Eighteen bacterial strains were individually assayed against *Gibberella pulicaris* by coinoculating antagonist and pathogen in wounds of the cultivar Russet Burbank. All antagonist decreased the disease. When four strains (*Enterobacter cloacae*, *Pantoea agglomerans*, *Pseudomonas corrugata* and *Pseudomonas fluorescens*) in pairs of antagonists they reduced disease by some 70% versus controls, a level of control comparable with that obtained with 100 times the inoculum dose of a single antagonist strain (Schisler *et al.* 1997). On the basis of experiments using a commercial peat-based medium containing *Glomus intraradix* (*G. intraradices*) it was suggested that the fungal inoculum has potential for use in suppression of tuber dry rot (Niemira *et al.* 1996).

Treatment of tubers with thiabendazole has been shown to control the disease. Treatment should be carried out directly after harvest to prevent the fungi getting established in wounds but resistance to the fungicide has been reported (Aprasad *et al.* 1997). In a study of 200 *Fusarium* isolates by Hanson *et al.* (1996), 82 grew at ± 5 mg L⁻¹ of thiabendazole and were considered tolerant of thiabendazole. These included isolates of *G. pulicaris*, *F. solani*, *F. oxysporum*, *G. acuminata* and *F. culmorum*. Thiabendazole tolerant isolates were obtained from most locations and all tuber types. Stored tubers were collected in Canada by Platt (1997) which had symptoms of *Fusarium* rot which had been treated commercially after harvest with thiabendazole. Tolerance of thiabendazole was detected in isolates of *F. sambucinum* (*G. pulicaris*) and *H. solani*, but not in isolates of *F. avenaceum* (*G. avenacea*) and *F. oxysporum*.

Fenpiclonil and the mixture of thiabendazole and imazalil were more effective in controlling dry rot than imazalil alone (Carnegie *et al.* 1998). The development of dry rot was, however, increased by 2-aminobutane treatment on 8 out of 14 stocks. 2-aminobutane gave the greatest reduction (83%) in the severity of skin spot during storage whereas thiabendazole alone, and the mixture of thiabendazole and imazalil, gave mean reductions of 70 and 65% respectively. The incidence of dry rot on daughter tubers was not reduced consistently by fungicide treatment of seed tubers of the six stocks tested. Li *et al.* (2012) found that borates were promising as a natural fungicide to partially substitute synthetic fungicides in the control of *Fusarium sulphureum* in tubers. They particularly found that the addition of borates significantly improved the effectiveness of thiabendazole to control dry rot but their effect were curative and were ineffective as a preventative treatment.

During the 1992–1993 and 1994–1995 potato winter storage period in Quebec, New Brunswick, and Prince Edward Island tolerance of thiabendazole was detected in isolates of *F. sambucinum* (*Gibberella pulicaris*), but not in isolates of *F. avenaceum* (*G. avenacea*) and *F. oxysporum*. However, the majority of the farms surveyed (64%) had adequate disease control with no pathogen isolated from the diseased tubers. Incidence and EC50 values of tolerant isolates were lower than those found elsewhere and the occurrence of farms with tolerant isolates of *G. pulicaris* (18%) While the study investigated commercial operations employing a wide range of thiabendazole rates (6–42 g a.i. tonne⁻¹), no specific trends were detected between the occurrence of tolerant isolates and cultivar or thiabendazole application rate (Platt 1997).

Frost injury

Frost injury occurs when the tubers are subject to temperatures at which the cell sap will begin to freeze (about –1.5 °C). Vascular tissues, especially those close to the tuber surface can be killed and turn black giving the disease of ring necrosis. Cultivated potato is frost sensitive, but it has several frost-tolerant wild relatives, one of which is *S. commersonii* (Seppanen *et al.* 1998). Calcium affects responses of tubers to stresses including those as a result of exposure to freezing temperatures (Palta 1996).

Gangrene

Gangrene is caused by infection with the fungus *Phoma foveata* (*P. exigua* var. *foveata*). Hide *et al.* (1995) showed that infections with *P. foveata* reduced tuber yield. Temperature and rainfall during a 40 days preharvest treatment affected levels of *P. foveata* (Bang 1992). There is evidence that some cultivars are more resistant than others to attack from *P. foveata*. Bradshaw *et al.* (1996) indicated that the progeny of crosses that showed gangrene resistance all had sizeable contributions from *Solanum tuberosum* subsp. *andigena* in their pedigrees.

In Sweden seed tubers were infected by *P. foveata* and treatment with benomyl or thiabendazole controlled the development of gangrene but did not consistently reduce the levels of infestation in progeny from treated seed tubers (Bang 1992). When applied as a pre-planting seed tuber treatment, fenpiclonil controlled gangrene to a commercially acceptable level (Leadbeater and Kirk 1992). Benomyl use is not permitted in many countries. From tubers infected with *P. foveata* infestation of the soil was greatest immediately around the tuber and was largely confined to a distance of 15 cm until haulm destruction, after which it was detected more widely in the soil (Carnegie and Cameron 1991). Potato tubers inoculated with *P. exigua* var. *foveata* were dipped or sprayed with fungicide immediately after wounding or after holding them at 5 or 15 °C for up to 14 days. Thiabendazole and 2-aminobutane, [(RS)-sec-butylamine], either separately or combined, controlled gangrene when applied soon after wounding. On tubers with little inoculum, application in 2 L tonne⁻¹ was better than in 400 ml tonne⁻¹. When treatment was delayed, (RS)-sec-butylamine or the mixture was more effective than thiabendazole alone. Adsorption of thiabendazole onto soil increased with decreasing soil pH and the fungicide gave better control of disease on tubers carrying neutral than acid soil (Hide and Cayley 1989).

Tuber contamination was much less when stems were pulled and removed than when they were desiccated by applying diquat dibromide. The incidence of tuber contamination did not increase between haulm destruction and harvest when stems were pulled and removed. Tuber contamination increased linearly with the delay in pulling haulms after applying diquat dibromide (Carnegie and Cameron 1991). The incidence of gangrene increased in cultivar Bellona after

spraying haulms with diquat. The lowest *P. exigua* var. *foveata* infection levels occurred after pulling haulms. Late harvesting increased the frequency of *P. exigua* var. *foveata* in cultivars Bintje and Bellona (Bang 1989).

Overall, 2-aminobutane was more effective in controlling gangrene in store than the spray-applied fungicides (Carnegie *et al.* 1998). Deposits of imazalil, thiabendazole and fenpiclonil were greater when sprays were applied with an electrostatic sprayer than with a hydraulic sprayer. The opposite was found with the mixture of prochloraz Mn and tolclofos-methyl. More effective gangrene control was associated with the highest deposits. The incidence of gangrene on daughter tubers was not reduced consistently by fungicide treatment of seed tubers of the six stocks tested.

Heal end rot

Possible the same disease as jelly end rot.

Herbicide damage

Symptoms on tubers can be similar to Verticillium rot, brown rot and ring rot and show up as a ring of vascular browning particularly at the heel end of the tuber. They are often caused by improper application of herbicides used to kill the haulm prior to harvesting.

Hollow heart

Hollow heart is a physiological disorder where cavity develops in the centre (pith region) of a tuber which is lined with cork but otherwise not discoloured. The cavity is angular and star or lens shaped. In a review Rex and Mazza (1989) it was shown that the development of the disorder is often associated with rapid tuber growth that may be preceded by a period of moisture or nutritional stress. Two or more types of hollow heart may exist. The cause of the disorder, the pattern of development, and the growth stage of the tuber differentiate them as the disorder develops. Management can affect the incidence of hollow heart by such methods as choice of cultivar, plant spacing, rate and timing of fertilizer application, and control of soil moisture. Snowden (1991) showed that it was caused by an irregular water supply giving uneven growth of the tuber. It commonly occurs when growth is accelerated when water availability increases after a drought and is

mainly associated with larger tubers. Kim *et al.* (1997) showed that hollow heart generally increased with delay in harvesting.

There are no surface indications of the disorder and several attempts have been made to develop non-destructive techniques for detection of tubers with hollow heart cavities. The most reliable and practical procedure developed to date for its detection in whole tubers, as well some other internal disorders, uses X-ray technology (Finney and Norris 1973).

The content of Ca in the soil is of less importance for the initiation and development of internal defects than the soil physical characteristics. If internal defects are caused by suboptimal supply of Ca to the tubers, this is more likely related to weather conditions than to a low content of exchangeable Ca in the soil. The K content in the soil seems to be important. Both brown centre and hollow heart are mostly initiated at early stages in tuber development, and the occurrence of internal defects increased with large fluctuations in temperature and precipitation early during crop growth (Gederaas 1996). A significant decrease in hollow heart with increasing rate of K fertilizer application was observed in 4 of 11 sites in different years (Panique *et al.* 1997).

Trials in which Atlantic and Daekwan-56 were either not mulched or mulched with clear or black polyethylene film or reflective film showed that hollow heart occurrence in Atlantic was highest with black polyethylene film and lowest with reflective film. In both cultivars occurrence of internal brown spot was lower with reflective film or no mulching than with either polyethylene film (Kim *et al.* 1997).

Impact bruising

Impact bruising of tubers results from either the tuber being dropped or something hitting it. The damage might be obvious on the surface or it might be internal such as blackspot. Internal blackening of potatoes is a common form of this latter affect and is temperature sensitive. It occurs more frequently when the tuber temperature is below 8 °C or above 20 °C (John Love 1995, personal communication). Even when the crop is protected within a fibre board box, impact damage can occur if the box is dropped. To avoid impact damage crops must be handled with great care. This is particularly the case where they are harvested and handled mechanically. Shutes and cushioned pads should be used to break the fall of

the crop and distances of fall should be kept to a minimum.

New and stored table stock potatoes packed in paper baler bags and in corrugated cardboard boxes were subjected to specific rough handling drops and sinusoidal vibration to determine the cause of shatter bruising. Impact shock rather than in-transit vibration caused the majority of the commercially significant bruising. Packaged potatoes dropped from heights of 80 cm or higher onto hard surfaces will begin to exhibit shatter bruising. Impacts of over 20–30 g between packages will also cause shatter bruising. Corrugated cardboard boxes provide slightly more protection than paper baler bags (Turczyn *et al.* 1986).

Skin spot

Buskila *et al.* (2011) reported the occurrence of irregular necrotic spots formed during storage and transport on early harvested tubers packed in large bags containing peat. They suggested that this was due to an over-suberization response to *Rhizoctonia solani* infection that occurred prior to tuber skin set.

Potato yam

Dioscoreaceae

Dioscorea bulbifera L. occurs in a wide variety of forms and many synonyms have appeared in the literature including *D. anthropophagorum* A.Chev., *D. crispata* Roxb., *D. heterophylla* Roxb., *D. hoffa* Cordem., *D. hofika* Jum. & H.Perrier, *D. korrorensis* R.Knuth, *D. latifolia* Benth., *D. longipetiolata* Baudon, *D. oppositifolia* Campbell, *D. papilaris* Blanco, *D. perrieri* R.Knuth, *D. pulchella* Roxb., *D. rogersii* Prain & Burkill, *D. sativa* Thunb., *D. tamifolia* Salisbury, *D. tenuiflora* Schldl., *D. violacea* Baudon, *D. tunga* Hamilton, *Hemia bulbifera* (L.) Kunth and *Polynome bulbifera* (L.) Salisb. Other common names include aerial yam, air potato, bulbil bearing yam, turkey liver yam, danda yam, igname bois, otaheite potato, papa caribe, air yam, aerial yam, bitter yam and cheeky yam.

It is common in its wild state throughout Africa and Asia. The African and Asian varieties are so distinct that evolution must have taken place in prehistoric times. There is disagreement as to whether the original source was in Southeast Asia or whether

there was also a centre of origin in Africa. The species is now common throughout the tropics (Kay 1987).

A strongly climbing vine, reaching 6 m or more, with smooth stems up to 8 mm in diameter. It produces edible bulbils in the leaf axils above ground and tubers below ground, although the latter are sometimes absent (Coursey 1967). The tubers are hard, bitter and unpalatable (Purseglove 1972). The bulbils are the main storage organs and are eaten and can weigh up to 2 kg but are more commonly around 500 g. They are grey or brown in colour with white or yellow mucilaginous flesh. The bulbils are normally cooked and eaten in a manner similar to other starchy root crops, though many African forms require detoxification by soaking in water or prolonged boiling before they are safe to consume. A few are very succulent and may be eaten raw. The flavour is reported to be inferior to that of most common yams and some are bitter (Kay 1987, Purseglove 1972). In Indonesia a fish poison is made from the bulbils of toxic varieties and in Africa poisonous varieties may be planted among safe varieties to discourage thieves. In India a folk medicine is made from the tuber. It is made into a paste and used as a cure for snakebite and in Jamaica it is used for treatment of scorpion and centipede stings (Kay 1987).

Knoth (1993) gave the following analysis on a fresh weight basis for tubers: 63–67% moisture, 27–33% carbohydrates, 0.1% fats and 1.1–1.5% crude protein. Opara (1999) reported that the content of the edible part of tubers per 100 g edible tuber portions was 71–79 g water, 1.4–1.5 g protein, 18–26 g carbohydrate and 0.9–1.2 g fibre. Data from Southeast Asia gave 62.6–66.9% water, 27–33% starch, 0.08–0.10% reducing sugars, 0.25–0.35% non-reducing sugars, 0.4% fat and 1.12–1.50% crude protein (Coursey 1967). Kay (1967) reported the fresh weight composition of the tubers as 69.1% water, 0.89% protein, 0.1% fat, 26.5% carbohydrate and 6.74% fibre. Shajeela *et al.* (2011) gave the following analysis for *D. bulbifera* var. *vera* for 100 g fresh weight of tuber: starch 38.10 ± 0.1 g, niacin 33.74 ± 0.21 g and ascorbic acid 91.04 ± 0.86 g. Martin *et al.* (1974) found that β -carotene was not detected in *D. bulbifera* and the yellow pigments of were xanthophylls. Shajeela *et al.* (2011) gave the following analysis for antinutritional factors for 100 g fresh weight: total free phenolics 2.20 ± 0.01 g, tannins 1.48 ± 0.10 g, hydrogen cyanide 0.19 ± 0.01 mg, total oxalate 0.78 ± 0.01 g, amylase

inhibitor 1.36 AIU mg⁻¹ soluble starch and trypsin inhibitor 1.21 ± 0.01 TIU mg⁻¹ protein. Kay (1987) reported that the proximate composition of the bulbils, in terms of the fresh weight, was 63–67% water, 1.12–1.5% protein, 0.04% fat, 27–33% carbohydrate, 0.7–0.73% fibre and 1.08–1.51% ash.

Harvesting

It may take 2 years from planting to harvesting (Kay 1987). Harvest maturity is when the vines begin to wither. At this point the bulbils may fall off naturally or they can easily be dislodged with a twist. Immature bulbils may be harvested 3–4 months after planting and harvesting may continue for the life of the plant of up to 2 years. Underground tubers are normally harvested when the vine dies back, which is after some 15–24 months (Kay 1987). Forks or other digging tool are used to harvest the tubers.

Curing

Both bulbils and tubers are resistant to fungal infections and when left in the shade in tropical ambient conditions harvest wounds heal quickly (Kay 1987).

Storage

The tubers may be left for several months in the soil until needed. The dormancy period of *D. bulbifera* from Nigeria was given as 14–16 weeks (Opara 1999). Kay (1987) indicated that both tubers and bulbils can be stored under dry cool conditions away from sunlight, which appears to give a moderate storage life.

Pumpkin, winter squash

Cucurbitaceae

Three species are called pumpkin and winter squash: *Cucurbita maxima* Duchesne ex Lam., *C. mixta* Pang and *C. moschata* (Duchesne ex Lam.) Duch. ex Poir. Two varieties are sometimes recognised for *C. maxima*, these are *C. maxima* var. *maxima* with cultivars including Mammoth, Hubbard, Delicious and Buttercup and *C. maxima* var. *turbaniformis* the Turban Squash. Cultivars of *C. mixta* include Cushaw and Japanese Pie and cultivars of *C. moschata* include Butternut, Kentucky Field, Sugar and Winter Crookneck

(Purseglove 1972). Purseglove also supplies a key for the identification of the three species and *C. pepo*. Brecht (2002a) gave the following names: for pumpkin or acorn squash *C. pepo* L., Winter Squash and Giant Pumpkin *C. maxima* Duchesne ex Lam. and crookneck squash, tropical pumpkin calabaza, or butternut squash *C. moschata* (Duchesne ex Lam.) Duchesne ex Poir. USDA (2012b) gave the following: *C. moschata* Duchesne for crookneck squash *C. maxima* Duchesne for winter squash, *C. maxima* Duchesne var. *turbaniformis* Alef. for turban squash, *C. maxima* Duchesne ssp. *andreana* (Naudin) Filov for winter squash and *C. mixta* Pang. for pumpkin. They are all monoecious vines with globular in shaped fruits and they will freeze at about –1.0 to –0.9 °C (Wright 1942). Purseglove (1972) gave the following descriptions:

- *C. maxima* has soft round moderately bristly stems. The fruits have a soft or hard shell, dull or brightly coloured, fine grained flesh, that is various shades or yellow with plump usually white or pale brown seeds that do not separate easily and cleanly from the pulp.
- *C. moschata* has smooth round or five angled moderately hard stems. The fruit have a soft dull coloured shell with yellow to dark orange fine to coarse-grained flesh with gelatinous fibres. Seeds are plump and off white to dark brown in colour that cleanly separate from the pulp.
- *C. mixta* has pilose not harsh five angled stems. The fruits have a soft or hard shell, usually dull in colour with white to pale tan or yellow coarse-grained soft flesh. Seeds are plump, white or tan in colour that cleanly separate from the pulp.

Purseglove (1972) reported that cultivation of *C. mixta* dates from 100 to 760 CE and is not so ancient as *C. pepo* and *C. maxima*. It seems to have been widely distributed in northern Mexico and southwestern USA in pre-Colombian times. No remains of *C. maxima* have been reported in Mexico or Central America but seeds have been excavated from Peru dated 1200 CE. He also reported that *C. moschata* was widely distributed throughout North and South America. In Peru it has been dated to 3000 BCE and in Mexico about 5000 BCE where it was thought to have been first cultivated and then distributed north and south because it can tolerate hotter conditions than

Table 110 The composition of pumpkin fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	91.60 g	Thiamine	0.050 mg
Energy	26 kcal	Riboflavin	0.110 mg
Protein	1.00 g	Niacin	0.600 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.061 mg
Carbohydrate, by difference	6.50 g	Folate	16 µg_DFE
Total dietary fibre	0.5 g	Vitamin B-12	0.00 µg
Sugars, total	1.36 g	Vitamin A	369 µg_RAE
Calcium	21 mg	Vitamin A	7384 IU
Iron	0.80 mg	Vitamin E (α-tocopherol)	1.06 mg
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	44 mg	Vitamin D	0 IU
Potassium	340 mg	Vitamin K (phyloquinone)	1.1 µg
Sodium	1 mg	Fatty acids, total saturated	0.052 g
Zinc	0.32 mg	Fatty acids, total monounsaturated	0.013 g
Total ascorbic acid	9.0 mg	Fatty acids, total polyunsaturated	0.005 g

other *Cucurbita*. The chemical content was given by USDA Nutrient Database (2012a) in Table 110.

Harvesting

They are harvested when they are fully mature and have reached an acceptable size, with golden yellow flesh and a good texture.

Curing

A 10–20 day curing period at 24–27 °C before storage can harden the rind of pumpkins and winter squashes (Gorini and Testoni 1978). However, in New York, curing for 3 weeks at 27 °C to heal mechanical injuries and to ripen immature specimens proved unnecessary (Platenius *et al.* 1934, Schales and Isenberg 1963). Curing Butternut, Hubbard and Quality squashes was of no value but had no harmful, whereas curing Table Queen was detrimental to skin colour, texture and taste and they decayed more rapidly than non-cured fruit (Schales and Isenberg 1963).

Postharvest physiology

They produce only trace amounts of ethylene, but Hubbard and other dark green skinned squashes

should not be stored near apples, as ethylene may cause the skin to turn orange-yellow and also cause stem abscission; especially in less mature fruit (Brecht 2002a). Brecht (2002a) also reported that the respiration rate was 88–110 mg CO₂ kg⁻¹ h⁻¹ at 12 °C for Buttercup and 61–121 mg CO₂ kg⁻¹ h⁻¹ at 25 °C for Butternut.

Storage

Pumpkins store very well and it was claimed that the cultivar Mammoth Cheese had been stored for as long as 17 months (Wardlaw 1937). Ryall and Lipton (1979) stated that the storage humidity should be 50–70% r.h. since higher humidity promoted decay while lower humidity caused excess weight loss and texture deterioration. However, storage recommendations were as follows:

- 12.8–15.6 °C and 70–75% r.h. for 2–3 months (Wardlaw 1937);
- 10–13 °C and 70–75% r.h. for 2–6 months (Anonymous 1967);
- 1.7–15.6 °C and 70–75% r.h. for 24–36 weeks with 3.7% loss (Pantastico 1975);
- 12.2 °C and 70–75% r.h. for 84–160 days (SeaLand 1991);
- 10–13 °C and 60–70% r.h. for 2–5 months (Snowdon 1991).

Storage recommendations for specified cultivars were as follows:

Butternut

- 6.7–10 °C and 70–75% r.h. for 2 months (Phillips and Armstrong 1967);
- 10 °C and 70–75% r.h. for 2–3 months (Anonymous 1968, Lutz and Hardenburg 1968);
- 10–16 °C and 60% r.h. for up to 50 days (Tindall 1983);
- 10 °C for 2–3 months (Brecht 2002a).

Connecticut Field

- 10–12.8 °C and 70–75% r.h. for 2–3 months (Anonymous 1968).

Cushaw

- 10–12.8 °C and 70–75% r.h. for 2–3 months (Anonymous 1968).

Hard skinned winter squash

- 12.2 °C with 70–75% r.h. for 84–150 days (SeaLand 1991).

Hubbard

- 6.7–10 °C and 70–75% r.h. for 6 months (Anonymous 1968, Phillips and Armstrong 1967);
- 10–16 °C and 60% r.h. for up to 180 days (Tindall 1983);
- 10–13 °C and 70% r.h. for 6 months (Brecht 2002a).

Table Queen

- 10 °C for 5–8 weeks (Brecht 2002a).

Turban

- 6.7–10 °C and 70–75% r.h. for 3 months (Anonymous 1968, Phillips and Armstrong 1967);
- 10 °C for 3 months (Brecht 2002a).

Controlled atmosphere storage

Storage in 1% O₂ + 7% CO₂ was recommended for Buttercup squash by Prange and Harrison (1993), but SeaLand (1991) stated that controlled atmosphere storage had only slight to no effect. Lin and Saltveit (1997) found that 5% O₂ + either 5% or 10% CO₂ had no beneficial effects on decay of the cultivar Spaghetti and in fact decay was actually greater in the controlled atmosphere storage than in air.

Diseases

Numerous fungi cause storage rots including species of *Aspergillus*, *Colletotrichum* (anthracnose), *Didymella*, *Fusarium*, *Mycosphaerella* (black rot), *Rhizopus* and *Sclerotinia* (Arvayo-Ortiz *et al.* 1994, Hawthorne 1990). Hot water treatment at 60 °C for 2 min reduced storage rots (Francis and Thomson 1965) while treatment at lower temperatures was not effective (Arvayo-Ortiz *et al.* 1994, Hawthorne 1990).

Purslane**Portulacaceae**

Portulaca oleracea L. It originated from the region extending from the western Himalayas to southern Russia and Greece. In Greece and other eastern Mediterranean countries and Central Asia it is found

in the wild and is also cultivated (Vavilov 1951). Nuez and Hernández Bermejo (1994) reported that De Candolle thought that this species was being cultivated more than 4000 years ago. After the 16th century, cultivation of purslane was gradually lost in Spain. They quoted Boutelou and Boutelou in 1801 as ‘purslane, which is not at all appreciated in Spain, is one of the crops which, in England and other countries further north, need to be cultivated in frames and hotbeds in order to bring forward their vegetation artificially’; and further on: ‘on this land, it is not usual to cultivate purslane other than using those that have grown at random among other plants cultivated with more care’. It is still valued in many Latin American countries where it was introduced. In England in the 17th century the cooks of Charles II used to add its leaves to all salads.

Purslane is an annual, herbaceous plant, with branched, decumbent or fairly ascending stems of up to 50 cm, and which are reddish, fleshy and glabrous. The leaves measure 0.5–3.3 × 0.2–1.5 cm, are obovate, entire and fairly papillose (Nuez and Hernández Bermejo 1994). Rinaldi *et al.* (2010) found that purslane was high in antioxidants and total phenols and their declined during storage was influenced by temperature. There was also a marked reduction in vitamin C during storage at 10 °C. The chemical content was given by USDA Nutrient Database (2012a) in Table 111.

Respiration rate and ethylene production increased with increasing storage temperature, although production of ethylene was very low at less than 1 nl k⁻¹ h⁻¹ at 10 °C. In storage at 15 °C exposure to ethylene at concentrations of 1 and 10 µl L⁻¹ affected respiration rate, colour and overall appearance. Exposure to ethylene at 0 °C had no apparent effects (Rinaldi *et al.* 2010). They also found that their maximum storage period for fresh leaves was 8 days 10 °C, 10 days at 5 °C and 13 days at 0 °C. No symptom of chilling injury was observed at any temperature but at 10 °C leaves had a higher chlorophyll loss compared to storage at 5 or 0 °C.

Queensland arrowroot**Cannaceae**

Canna indica L. synonymous with *C. edulis* Ker-Gawl. Other common names include Australian arrowroot

Table 111 The composition of purslane for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.92 g	Folate, DFE	12 µg_DFE
Energy	16 kcal	Choline, total	12.8 mg
Energy	67 kJ	Vitamin B-12	0.00 µg
Protein	1.30 g	Vitamin A	66 µg_RAE
Total lipid (fat)	0.10 g	Retinol	0 µg
Ash	1.25 g	Vitamin A	1320 IU
Carbohydrate, by difference	3.43 g	Vitamin D (D2 + D3)	0.0 µg
Calcium	65 mg	Vitamin D	0 IU
Iron	1.99 mg	Tryptophan	0.014 g
Magnesium	68 mg	Threonine	0.044 g
Phosphorus, P	44 mg	Isoleucine	0.047 g
Potassium, K	494 mg	Leucine	0.080 g
Sodium, Na	45 mg	Lysine	0.057 g
Zinc, Zn	0.17 mg	Methionine	0.012 g
Copper, Cu	0.113 mg	Cystine	0.009 g
Manganese, Mn	0.303 mg	Phenylalanine	0.051 g
Selenium, Se	0.9 µg	Tyrosine	0.021 g
Vitamin C, total ascorbic acid	21.0 mg	Valine	0.063 g
Thiamine	0.047 mg	Arginine	0.050 g
Riboflavin	0.112 mg	Histidine	0.020 g
Niacin	0.480 mg	Alanine	0.050 g
Pantothenic acid	0.036 mg	Aspartic acid	0.068 g
Vitamin B-6	0.073 mg	Glutamic acid	0.191 g
Folate, total	12 µg	Glycine	0.040 g
Folic acid	0 µg	Proline	0.061 g
Folate, food	12 µg	Serine	0.039 g

and edible canna. The genus *Canna* includes about 25 species of herbs, originated from the Andean region or Peruvian coast. *C. indica* probably originated in the Andean region and there is evidence of its cultivation on the Peruvian coast about 2500 BCE. It now extends throughout the Amazon basin and from Venezuela to northern Chile. In the West Indies it has become naturalized and has been spread to parts of Australia, Polynesia and Africa (Kay 1987). It is cultivated in Australia for the production of starch, whereas in India, it is grown for its edible tuberous rhizome. The plant is hardy and has low incidence of pests and diseases (Edison *et al.* 2006).

It is a root crop that produces clusters of edible rhizomes up to 60 cm long with fleshy segments that superficially resemble corms and which are greyish white in colour with violet scales. In the Andes two clones are recognized *Verdes* with grey/white corms and bright green foliage, and *Morados* with

corms covered with violet coloured scales (Kay 1987). Analysis of the rhizomes has been given as water 67–72%, carbohydrate 24–30%, protein 1–1.7%, fat 0.1%, fibre 0.6%, ash 1.4%, calcium 18 mg 100 g⁻¹, phosphorus 63 mg 100 g⁻¹ and ascorbic acid 7 mg 100 g⁻¹. The percentage of starch varied with the age of the rhizomes and was usually at a maximum between 6 and 15 months when the sucrose content was also high. The cysteine level in the protein was very low (Kay 1987).

Harvesting

Harvest maturity may be anything between 6 and 19 months after planting depending on the climate of the country where they are grown the use that will be made of the rhizomes. The rhizomes are produced just below the soil surface and are harvested by hand by pulling and levering or mechanical harvesters are available (Kay 1987).

Storage

They can be stored for several weeks without deterioration in a cool dry place. In Japan they were often stored over winter in field pits 30 cm deep (Kay 1987).

Radish

Cruciferae

Raphanus spp. Kay (1987) reported that four varieties of *R. sativus* are recognized: *radicula*, *niger*, *mougri* and *oleifera*, with *radicula* and *niger* grown for their edible roots. Numerous cultivars have been developed within each variety. All varieties intercross freely and also hybridize with wild *Raphanus* spp. Daikon is *R. sativus* var. *acanthiformis*, while Chinese radish or Japanese radish is *R. sativus*, var. *longipinnatus*, *R. sativus* L. var. *hortensis* Backer, *R. sativus* L. var. *longipinnatus* Bailey or *R. sativus* L. var. *niger* (Miller) Persoon. Wild radish was given as *R. raphanistrum* L., rat-tailed radish as *R. caudatus* and black radish as *R. sativus* var. *niger*. The edible portion is the swollen taproot, which is small, round or oval in shape with a red skin and white pungent flesh and is used in salads. In Greek *Raphanus* means 'quickly appearing', which refers to their rapid germination, and in Latin radish is derived from *radix*, which means root (Lewis-Jones *et al.* 1982).

Wild forms of *Raphanus* spp. are found in Western Asia and Europe (Lewis-Jones *et al.* 1982) particularly between the eastern Mediterranean and the Caspian sea. *Raphanus sativus* var. *niger* was an important food in Egypt probably as early as 2700 BCE and is thought to have spread to China by about 500 BCE and to Japan by 700 CE. Kay (1987) reported that *R. sativus* var. *radicula* was first reported in the 16th century in Europe. The globular forms of salad radish were developed from *R. sativus* var. *radicula* in the 19th century. Daikon was said to have originated in the Mediterranean and taken to China for cultivation around 500 BCE. The word Daikon actually comes from two Japanese words *dai* meaning large and *kon* meaning root.

The average composition of the edible roots has been reported by Kay (1987) as energy 86.7 kJ 100 g⁻¹, water 93.5%, carbohydrate 3.85%, protein 1.05%, fat 0.15%, carbohydrate 3.85%, fibre 0.7%, ash 0.75%, boron 2.08 mg 100 g⁻¹, calcium 33 mg 100 g⁻¹, chlorine 19 mg 100 g⁻¹, copper 0.13 mg 100 g⁻¹, iodine 8 mg 100 g⁻¹, iron 0.8 mg 100 g⁻¹, magnesium 15 mg 100 g⁻¹, manganese 0.05 mg 100 g⁻¹, phosphorus 29 mg 100 g⁻¹, potassium 322 mg 100 g⁻¹, sodium 18 mg 100 g⁻¹, carotene 0.006 mg 100 g⁻¹, thiamine 0.03 mg 100 g⁻¹, riboflavin 0.03 mg 100 g⁻¹, niacin 0.4 mg 100 g⁻¹, pantothenic acid mg 100 g⁻¹, ascorbic acid 0.029 mg 100 g⁻¹, glucose 640 mg 100 g⁻¹, fructose 390 mg 100 g⁻¹, campesterol mg 100 g⁻¹ and sitosterol mg 100 g⁻¹. The characteristic pungent flavour of the roots is due to the presence of isothiocyanates, while the coloured cultivars contain anthocyanins which are reported to occur as naturally acylated, with either ferulic or *p*-coumaric acids. Catechol has been reported in the red cultivars and flavanols have been detected in minute quantities. Weichmann (1987) reported that their water content was about 93% and they contained on a fresh weight basis 26 mg vitamin C, 0.03 mg thiamine, 0.03 mg riboflavin, 0.08 mg pyridoxine and 10 international units of vitamin A 100 g⁻¹. Glucoraphasatin, a glucosinolate, is the major pungent component in radish root and has antifungal, antibacterial and direct preventive antioxidant activity (Montaut *et al.* 2010). The chemical content was given by USDA Nutrient Database (2012a) in Table 112.

Table 112 The composition of radish for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	95.27 g	Vitamin C, total ascorbic acid	14.8 mg
Energy	16 kcal	Thiamine	0.012 mg
Energy	66 kJ	Riboflavin	0.039 mg
Protein	0.68 g	Niacin	0.254 mg
Total lipid (fat)	0.10 g	Pantothenic acid	0.165 mg
Ash	0.55 g	Vitamin B-6	0.071 mg
Carbohydrate, by difference	3.40 g	Folate, total	25 µg
Total dietary fibre	1.6 g	Folic acid	0 µg
Sugars, total	1.86 g	Folate, food	25 µg
Sucrose	0.10 g	Folate	25 µg_DFE
Glucose (dextrose)	1.05 g	Choline, total	6.5 mg
Fructose	0.71 g	Betaine	0.1 mg
Lactose	0.00 g	Vitamin B-12	0.00 µg
Maltose	0.00 g	Vitamin A	0 µg_RAE
Galactose	0.00 g	Retinol	0 µg
Starch	0.00 g	Carotene, β	4 µg
Calcium	25 mg	Carotene, α	0 µg
Iron	0.34 mg	Cryptoxanthin, β	0 µg
Magnesium	10 mg	Vitamin A	7 IU
Phosphorus	20 mg	Lycopene	0 µg
Potassium	233 mg	Lutein + zeaxanthin	10 µg
Sodium	39 mg	Vitamin E (α-tocopherol)	0.00 mg
Zinc	0.28 mg	Vitamin D (D2 + D3)	0.0 µg
Copper	0.050 mg	Vitamin D	0 IU
Manganese	0.069 mg	Vitamin K (phylloquinone)	1.3 µg
Selenium	0.6 µg	Fatty acids, total saturated	0.032 g
Fluoride	6.0 µg	Fatty acids, total monounsaturated	0.017 g

Harvesting

This is when they are young and tender and reach a size that is acceptable to the market. If they are over mature they become fibrous, tough, hollow and eventually produce a flower stalk. They are pulled from the soil and either bunched with their leaves still attached or the tops are cut-off for marketing.

Pre-cooling

Rapid cooling is essential to achieve the full storage potential of both bunched and topped roots (Suslow 2000). Hydrocooling was the most suitable method but cooling with both high humidity and air cooling in a conventional cold store were also

suitable and vacuum cooling was generally unsuitable (MAFF n.d.). Both top icing and hydrocooling were recommended to retain their crispness by Lutz and Hardenburg (1968) and Kay (1987) recommended hydrocooling to 4 °C and Suslow (2000) recommended top icing. Holmes and Kemble (2009) recommended forced air cooling or hydrocooling for radishes grown in the southern United States.

Postharvest physiology

Rates of ethylene production are very low; less than $0.1 \text{ ml kg}^{-1} \cdot \text{h}^{-1}$ at 20 °C and they are reported to be not sensitive to ethylene but bunched tops may exhibit yellowing with prolonged exposure (Suslow 2000). After 10 days of storage at 1 °C del Aguila *et al.* (2006) found that their respiration rate was $1.59 \mu\text{g CO}_2 \text{ kg}^{-1} \text{ s}^{-1}$. They also found that whole roots stored at 1 °C showed the lowest respiration rate that was $1.59 \mu\text{g CO}_2 \text{ kg}^{-1} \text{ s}^{-1}$ while the highest rate was observed in shredded roots stored at 10 °C that was $7.42 \mu\text{g CO}_2 \text{ kg}^{-1} \text{ s}^{-1}$. Respiration rates, in $\text{ml CO}_2 \text{ kg}^{-1} \cdot \text{h}^{-1}$, for topped radishes were 2–4 at 0 °C, 3–5 at 5 °C, 6–7 at 10 °C and 19–26 at 20 °C. For bunched radishes they were 6–7 at 0 °C, 8–9 at 5 °C, 14–16 at 10 °C and 58–62 at 20 °C (Suslow 2000). Weichmann (1987) reported that their respiration rate was 5–10 $\text{CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ at 5 °C. Respiration rates are given in Table 113.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 1 day with their tops still attached and 2 days if the tops are removed. Tindall (1983) also found that roots with leaves attached have approximately half the storage life of topped roots. Suslow (2000) reported that even short exposure to temperatures above 7 °C will

result in the development of off-flavours, browning, and soft rot. They will freeze at about -2.8 to -2.3 °C (Wright 1942) or -1.22 to -0.72 °C (Weichmann 1987). General refrigerated storage recommendations were as follows:

- 0 °C and 90–95% r.h. for 3–4 weeks (Anonymous 1967, Phillips and Armstrong 1967, Lutz and Hardenburg 1968);
- 0 °C and high humidity for 28 days with about 10% weight loss (Tindall 1983);
- 7 °C for less than 7 days (Tindall 1983);
- 0 °C and 95–100% r.h. for 21–28 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 1–4 weeks (Snowdon 1991);
- 0 °C 95–100% r.h. for 3–4 weeks for radishes grown in the southern United States (Holmes and Kemble 2009).

Without Their Leaves (Topped)

- 0 °C and 90% r.h. for 3–4 weeks (Wardlaw 1937);
- 7.2 °C for at least a week (Lutz and Hardenburg 1968);
- 0 °C and 88–92% r.h. for 3–5 weeks with 8% loss (topped) (Pantastico 1975);
- 0–1 °C and 90–95% r.h. for 10–14 days (Mercantilia 1989);
- 2–5 °C and 90–95% r.h. for 7–10 days (Mercantilia 1989);
- 0 °C and 95–100% r.h. for 21–28 days (Suslow 2000).

With Their Leaves (Bunched)

- 0 °C and 90–95% r.h. for 1–2 weeks (Phillips and Armstrong 1967, Hardenburg *et al.* 1990);
- 0–1 °C and 90–95% r.h. for 3–5 days (Mercantilia 1989);
- 2–5 °C and 90–95% r.h. for 2–3 days (Mercantilia 1989);
- 0 °C and 95–100% r.h. for 7–14 days (Suslow 2000).

It was recommended to store fresh-cut sliced and shredded radishes at 1 or 5 °C in order to maintain their quality for 10 days (del Aguila *et al.* 2006).

Controlled atmosphere storage

Low O₂ storage was shown to prolong their postharvest life (Haard and Salunkhe 1975). Lipton (1972)

Table 113 Respiration rates of radish at different temperatures in carbon dioxide per kilogram per hour (source: adapted from Hardenburg *et al.* 1986)

Temperature (°C)	Topped roots	Bunched roots with tops
0	14–17	3–9
4–5	19–21	6–13
10	31–36	15–16
15–16	70–78	22–42
20–21	124–136	44–58

showed that storage of topped radishes at 5 or 10 °C in 1% O₂ reduced sprouting by about 50% compared to those stored in air. Although storage in 0.5% O₂ further reduced sprouting it resulted in physiological injury. Storage at 0.6 °C in 5% O₂ or 5 or 10 °C in 1–2% O₂ was recommended by Pantastico (1975). Saltveit (1989) recommended 0–5 °C in 2–3% CO₂ + 1–2% O₂ for topped radishes but indicated that controlled atmosphere storage had only a slight effect (SeaLand 1991). Weichmann (1987) also found that CO₂ had no beneficial effects but levels greater than 3% resulted in a higher respiration rate, increased decay and less intense red colour, while storage in low O₂ levels could result in off flavours. Suslow (2000) reported that 5–7 °C with 1–2% O₂ and 2–3% CO₂ was slightly beneficial in maintaining quality of topped radish and that controlled atmosphere storage helped to retard the regrowth of shoots and rootlets in topped radishes. Conversely Weichmann (1987) reported that storage in low O₂ levels could result in regrowth of roots. When temperatures were higher than 0 °C, storage in 1% O₂ was beneficial in reducing tip, root growth and softening (Lutz and Hardenburg 1968).

Hypobaric storage

Ward (1975) found no benefit in storage in 70 mm Hg compared to storage in atmospheric pressure. McKeown and Loughheed (1981) reported that during 7–28 days of storage at 1 °C in 55–60 mm Hg the weight losses were similar to the levels reported for controlled atmosphere storage with 2% O₂ and slaked lime to control CO₂. However, off-flavours developed in the controlled atmosphere stored radishes but not in those in hypobaric storage. Bangerth (1974) found that in storage at 2.2–2.8 °C and 95% r.h. there was a decrease in protein, ascorbic acid and chlorophyll losses in 75 mm Hg compared to storage in the same conditions in atmospheric pressure.

Diseases

Fatima *et al.* (2009) found *Fusarium solani*, *Cladosporium* sp. and *Drechslera australiensis* infecting radishes in on the market in Karachi, Pakistan with *F. solani* the most common. Other postharvest diseases include

- Bacterial black spot (*Xanthomonas vesicatoria*) produces lesions that are initially brown and has a diameter of up to 2.5 mm, but they eventually turn black and coalesce. Washing in water containing 100–200 µl L⁻¹ of chlorine gives some control.
- Downy mildew (*Peronospora parasitica*) produces purplish-red to brown surface lesions that may become rough and cracked, while the internal tissue can become greyish brown to black.
- Rhizoctonia root rot (*Rhizoctonia solani*) produces lesions that are initially round and light brown that may become slightly sunken with spongy tissue. High humidity and bruising can favour the disease.

Hydrocooling to 4.4 °C and storage at 0–1.7 °C helped to control these postharvest diseases (Ryall and Lipton 1979).

Rakkyo

Alliaceae, Liliaceae

Allium chinense G. Don synonymous with *A. bakeri* Regel also called ch'iao t'ou. It is native to Central and Eastern China and is now grown in much of eastern Asia where it is used mainly for pickles (Purseglove 1972). It produces small bulbs in clumps with solid scapes. Sulphur compounds accounted for 94% of the total volatiles in the isolated extract of rakkyo. In addition to the sulphur compounds commonly reported in the genus *Allium*, 27 novel volatile sulphur-containing components were found in the isolated extracts. Among them were a sulphide, disulphides, trisulphides and tetrasulphides with ethyl, butyl and pentyl groups (Jorge *et al.* 2001).

Rocket

Brassicaceae, Cruciferae

Eruca sativa Mill. synonymous with *E. vesicaria* subsp. *sativa* (Miller) Thell., *Brassica eruca* L. Wild rocket is *Diplotaxis tenuifolia* L. Other common names include arugula, roquette and rucola. It is distributed all around the Mediterranean, extending to central Europe in the north and as far as Afghanistan and northern India in the east. It has reverted to the wild state in North America, South Africa and Australia. Vavilov (1951) described it in central Asia, the Near East and the Mediterranean,

the latter being considered its main centre of origin. The edible portion is the young leaves that are consumed either raw or cooked. The term *baby rocket* refers to those harvested when only a few weeks old.

Rocket is an annual herbaceous plant, growing up to 80 cm. The basal leaves occur in a rosette and are lyrate-pinnatifid (those normally eaten in salads); the caulinar leaves are lobulate or dentate (Nuez and Hernández Bermejo 1994). Its characteristic bitter flavour is due to glucosinolates and the high content of mineral salts (Nuez and Hernández Bermejo 1994).

Postharvest physiology

They have low ethylene production but are highly sensitive to ethylene exposure that results in loss of chlorophyll leading to yellowing of leaves (Cantwell 1997). She also gave typical respiration rates as 42 at 0 °C and 113 mg CO₂ kg⁻¹ h⁻¹ at 5 °C.

Washing

Martínez-Sánchez *et al.* (2006) tested alternative sanitizers to 100 mg L⁻¹ chlorine for washing wild rocket leaves (*Diplotaxis tenuifolia*) and found that acidified sodium chlorite at 250 mg L⁻¹ and peroxyacetic acid at 300 mg L⁻¹ were effective with good retention of sensory quality and no detrimental reduction of the antioxidant constituents during storage at 4 °C.

Storage

Whole plants are sometimes sold with roots attached, which lengthens postharvest life. Storage recommendations include 0–2 °C and 90–98% r.h. (Thompson 1996) and 0–2 °C and 95–100% r.h. for 7–10 days (Cantwell 1997). Koukounaras and Siomos (2007) reported that storage at 0 or 5 °C resulted in slight deterioration over 13 days. At 10 °C they deteriorated rapidly and had a maximum shelf life of 8 days. Chlorophyll degradation was the most important deteriorative factor resulting in yellowing. Rogers *et al.* (n.d.) found that for maintaining postharvest shelf life of baby leaf rocket it must be vacuum cooled to 0 °C within half an hour of harvest to achieve the longest shelf life and the longer vacuum cooling is delayed, the shorter their shelf life. Storage temperature was also critical with storage at 0 °C maintaining both visual quality and vitamin C for a longer period than those stored at 4 or 7 °C.

Koukounaras *et al.* (2009) found that dipping leaves in water at 50 °C for 20–40 s retarded yellowing without damaging the leaves. Although 50 °C for 30 s accelerated ethylene production in packaged rocket leaves, it extended their postharvest life at 8 °C from 5 to 10 days without any appreciable effect on their quality. Nicola *et al.* (2004) reported that during storage of *E. sativa* grown in soilless conditions, at 4 °C for 8 days their quality index fell from 60.9 to 16.4% and they lost some 12% in fresh weight. Quality index was defined as 100% for the highest marketable value.

Controlled atmosphere storage

Martínez-Sánchez *et al.* (2006) stored wild rocket leaves (*Diplotaxis tenuifolia*) at 4 °C in 1–3% O₂ + 11–13% CO₂ for 15 days. The vitamin C content was maintained for up to 8 days of storage in air and low O₂ + high CO₂. A clear decrease in ascorbic acid followed by an increase in dehydroascorbic acid was observed in low O₂ + high CO₂. The content of flavonoids remained almost constant throughout the storage in air, but marked reductions were observed in low O₂ + high CO₂. The glucosinolates were the most affected constituents of rocket leaves as the content was reduced from 4 to 33% when samples were stored in air while the decrease was between 60 and 100% in low O₂ + high CO₂.

Modified atmosphere packaging

Løkke *et al.* (2012) stored wild rocket leaves packed on trays wrapped in film with either a low O₂ transmission rate (OTR) of 0.65 pmol s⁻¹ m⁻² kPa⁻¹ or a high OTR of 17.4 pmol s⁻¹ m⁻² kPa⁻¹ and stored them at 2, 10 or 20 °C. At low OTR, the O₂ concentration decreased to ≤0.5% and the leaves developed a 'smoked odour', lost leaf integrity and texture and turned olive-brown. At high OTR, the O₂ concentrations inside the package remained at 10–18%, and leaves showed signs of senescence, i.e. light-green to yellow leaves and a heterogeneous appearance of leaves in the tray. Koukounaras *et al.* (2009) and Koukounaras *et al.* (2010) showed that during storage at 8 °C for 7 and 14 days in modified atmosphere packaging whether they were stored as whole leaves or cut into two or four before placing them in the package did not affect their metabolic activity.

Runner beans

Fabaceae, Leguminosae

Phaseolus coccineus L. also called scarlet runner beans. It originated in Mexico and Guatemala where it grows wild at about 1800 m but is now widely distributed throughout the world in temperate climates. They rarely set seed in the lowland tropics. Runner beans have been found in Mexico that date back to 7000–5000 BCE but these were probably from wild plants and evidence of cultivation at Tehuacan has been dated to 200 BCE (Purseglove 1972).

It is a perennial twining plant that can grow up to some 4 m high. The edible portion is the pod of the fruit, which is called a legume. Pods are normally up to 30 cm long and contain up to 10 seeds. It is a non-climacteric fruit. In some cases the seed is allowed to develop and they are harvested as dry beans. Harvest maturity is normally when the seeds are just beginning to form within the pod. If harvesting is delayed the pod becomes stringy. In Britain they are usually harvested on a 4 to 5 day cycle. In storage at low temperatures the pods may develop brown discolouration, however, refrigerated storage recommendations were 4.5 °C for up to 7 days (Fidler 1963) and 0–6 °C and 85–90% r.h. for 1–3 weeks (Anonymous 1967).

Salsify

Compositae

Tragopogon porrifolius var. *sativus* (Gaterau) Br.-Bl. Other common names include vegetable oyster and oyster plant. It is a native of Eurasia or southern Europe (Harrison *et al.* 1985) where it was cultivated for its edible tap root. It is called the vegetable oyster because of its flavour. It is eaten boiled, baked or in soups and the tender young leaves can be used in salads. It is usually a biennial and the edible portion is the swollen taproot, which has a whitish skin and white flesh (Figure 52). They are up to 30 cm long with a diameter of 2–2.5 cm. Black salsify (*Scorzonera hispanica* L.) has a larger more cylindrical taproot that has brown to black skin and also white flesh. The salsify root is a raw material richer in compounds of low degree of polymerization, with sucrose as the main component (25.4%, corresponding to 75.6% of the total sugars). These data disagree with some literature



Figure 52 Salsify on the wholesale market in London in Britain in 1979.

Table 114 The composition of salsify for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	77.00 g	Zinc	0.38 mg
Energy	82 kcal	Total ascorbic acid	8.0 mg
Protein	3.30 g	Thiamine	0.080 mg
Total lipid (fat)	0.20 g	Riboflavin	0.220 mg
Carbohydrate,	18.60 g	Niacin	0.500 mg
by difference			
Total dietary	3.3 g	Vitamin B-6	0.277 mg
fibre			
Calcium	60 mg	Folate	26 µg_DFE
Iron	0.70 mg	Vitamin B-12	0 µg
Magnesium	23 mg	Vitamin A	0 µg_RAE
Phosphorus	75 mg	Vitamin A	0 IU
Potassium	380 mg	Vitamin D (D2 + D3)	0 µg
Sodium	20 mg	Vitamin D	0 IU

reports which consider salsify root as an inulin source (Beirão da Costa *et al.* 2005). The chemical content was given by USDA Nutrient Database (2012a) in Table 114.

Mencarelli (2002c) gave the respiration rate of the taproot as 22–28 at 0 °C, 33–53 at 5 °C, 40–57 at 10 °C and 193 mg CO₂ kg⁻¹ h⁻¹ at 20 °C. The crop will freeze at about –1.6 to –1.3 °C (Wright 1942) or –1.1 °C (Weichmann 1987) but is not injured by light freezing but should be handled with care in this condition (Lutz and Hardenburg 1968). They can be stored in traditional clamps. Refrigerated storage recommendations were 0 °C and 90–95% r.h. for 2–4 months (Wardlaw 1937, Hardenburg *et al.* 1990) and 0 °C and 95–100% r.h. for 60–100 days (SeaLand 1991). Controlled atmosphere storage at 0 °C with

3% CO₂ and 3% O₂ was recommended (Hardenburg *et al.* 1990), but controlled atmosphere storage was said to have only a slight effect or no effect (SeaLand 1991).

Mencarelli (2002c) reported that the most frequent diseases in the field were *Albugo tragopogonis*, causing russet spotting on leaves and powdery mildew (*Erysiphe cichoriacearum* DC.), which compromised quality.

Scorzonere

Compositae

Scorzonera hispanica L. Other common names include black salsify, Spanish salsify, black oyster plant, serpent root, viper's herb and viper's grass. It is native to southern Europe and the Near East but it is generally thought to have spread to the rest of Europe from Spain. The first mention by a western writer was probably Leonhard Rudolf, who reported seeing scorzonera at the market of Aleppo in Syria, in 1575. Although scorzonera was perhaps first cultivated in Spain, its cultivation has never been very important there. Boutelou and Boutelou (1801, quoted by Nuez and Hernández Bermejo 1994) commented: 'Scorzonera is usually sown on the edges of unoccupied beds, the empty spaces being profitably used by this tasty root' (Nuez and Hernández Bermejo 1994). Scorzonere roots are eaten boiled, baked or in soups in a similar way to salsify roots, but they have a sweetish flavour. The tender young leaves can also be used in salads. It is a perennial plant with yellow and sometimes rose-coloured flowers. It has a long, carrot-shaped fragile taproot, which is blackish on the outside and white and milky inside (Nuez and Hernández Bermejo 1994). Their highest freezing point is -1.1°C (Weichmann 1987). The taproot does not contain starch but it does contain inulin, which is an uncommon storage carbohydrate, but it is found particularly in some genera of Compositae and can be eaten by diabetics. The content of carbohydrates was given as 18–20% of the fresh weight, with a high proportion of inulin and laevulin. Inulin consists of a mixture of fructose polymers, with a chain length from 2 to 60 or 70 units, usually with a terminal unit of glucose (Beirão da Costa *et al.* 2005). It also contains the glucoside conopherin as well as asparagine, arginine, histidine and choline (Nuez

Table 115 The composition of scorzonere roots for 100 g⁻¹ fresh weight (source: adapted from Morton 1987; Ciquel 1995)

	Tinned	Cooked
Energy (kcal)	27	34
Proteins (g)	2.2	2.6
Carbohydrates (g)	4.1	4.9
Fat (g)	0.2	0.4
Fibres (g)	8	9
Sodium (mg)	560	18
Potassium (mg)	238	263
Vitamin E (mg)	2.5	3
Vitamin B-9 (μg)	12	20

and Hernández Bermejo 1994). Dolota *et al.* (2005) studied the cultivars Duplex, Lange Jan, Maxima, Prodola, Westlandia, Einjährige Riesen and Meres. The chemical content was given by Ciquel (1995) in Table 115.

Harvesting and handling

In Europe they are usually harvested in autumn. Nuez and Hernández Bermejo (1994) reported that sometimes the roots of scorzonera can begin to be used the first year after sowing, but they tend to be thin and a waste to harvest them so young. They required 2 or sometimes 3 years for their root to form to an acceptable size. Salsify has a similar taste and chemistry forms a tap root that is of sufficient size for harvesting in the first year. They can withstand heavy frost periods therefore harvesting can be delayed and they can be stored in the soil. In Belgium it was reported that the dry matter content was lower in later harvests, but in Poland there was no effect of harvest date (Weichmann 1987). The crops harvested in early December showed considerably lower inulin levels compared to those harvested in early-October or mid-November. The inulin content as well as the reducing sugar content is a useful parameter to determine the maturity of the scorzonera (Vulsteke and Calus 1990). When the roots are damaged they exude a milky sap that darkens when in contact with air and are therefore usually cooked by boiling with their skins in tact. Weichmann (1987) reported that the broken roots could be stored with minimal losses since the milky fluid exuded from the damaged areas may facilitate callus production.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 5–7 days. They are susceptible to shrivelling therefore humidity above 96% r.h. was recommended, since during 4 months of storage at 0 °C weight loss was 7.1% in 93% r.h. and only 4.7% in 97% r.h. (Weichmann 1987). Refrigerated storage recommendations were as follows:

- 0 °C and 90% r.h. for 4 months (Mercantilia 1989);
- 0 °C and 95–98% r.h. for 56–84 days (SeaLand 1991).

Stoll (1974) reported excellent results from storage at 0 °C in 3% CO₂ + 3% O₂ for 6 months. Weichmann (1987) recommended the use of perforated plastic films or the 'Marcellin-Teinturier' system to maintain high storage humidity, but there is no mention of any modified atmosphere effect.

Shallots

Alliaceae, Liliaceae

Allium cepa L. var. *aggregatum* G. Don. For many years they were considered to be a separate species to onions and given the name of *A. ascalonicum*, but they are now considered to be *A. cepa* and belong to the *aggregatum* group. Shallots differ from onion in that they multiply while they are still growing and produce many lateral bulbs. They are mainly used for pickling. The leaves are as valuable as the immature bulbs as they contain vitamin A, vitamin C and folate (Comadug and Simon 2002). The chemical content was given by USDA Nutrient Database (2012a) in Table 116. Total world production of green onions including shallots in 2010 was estimated by FAO (2012) as 3,912,739 tonnes.

Preharvest factors

Woldetsadik and Workneh (2010) found that with a basic dressing of 92 kg ha⁻¹ P₂O₅ increasing N levels (0, 50, 75 or 100 kg ha⁻¹) showed proportional increase in the bulb pungency levels, but the dry matter, TSS, total sugars and reducing sugars were not significantly affected either at harvest or during storage. However, there were increments in percentage of bulb rotting, sprouting and weight loss with increased N levels.

Table 116 The composition of shallots for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	79.80 g	Thiamine	0.060 mg
Energy	72 kcal	Riboflavin	0.020 mg
Protein	2.50 g	Niacin	0.200 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.345 mg
Carbohydrate, by difference	16.80 g	Folate	34 µg_DFE
Total dietary fibre	3.2 g	Vitamin B-12	0.00 µg
Sugars, total	7.87 g	Vitamin A	0 µg_RAE
Calcium	37 mg	Vitamin A	4 IU
Iron	1.20 mg	Vitamin E (α-tocopherol)	0.04 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	60 mg	Vitamin D	0 IU
Potassium	334 mg	Vitamin K (phylloquinone)	0.8 µg
Sodium	12 mg	Fatty acids, total saturated	0.017 g
Zinc	0.40 mg	Fatty acids, total monounsaturated	0.014 g
Total ascorbic acid	8.0 mg	Fatty acids, total polyunsaturated	0.039 g

Harvesting and handling

In Britain there is a proverb that says 'plant on the shortest day and harvest on the longest day'. They are harvested by undercutting the bulbs and pulling them from the ground, either by hand or using an onion harvesting machine. The timing of harvesting should be decided based on the considerations that relatively early harvesting favour better skin retention while later harvesting maximizes yields. Therefore, time of harvest is a compromise between maximum yield and maximum storage life and skin quality. Bulbs harvested at 75% top fall had higher dry matter content, less rotting, sprouting and weight loss. The result of a study by Woldetsadik and Workneh (2010) has shown N application of 50, 75 or 100 kg ha⁻¹, harvesting at 75% top fall and curing bulbs before foliage removal was a good compromise for yield, postharvest quality and shelf life in ambient storage.

Storage

Bulbs are commonly dried and normally stored and transported in slatted or open-mesh bags (Comadug and Simon 2002). High nitrogen content in bulbs, early harvesting and poor postharvest handling were

associated with short keeping quality in Thailand (Ruaysoongnern and Midmore 1994). Snowdon (1991) recommended 0–1 °C and 95–100% r.h. for 1–2 weeks but since the bulbs are closely related to the bulb onion (*A. cepa*) the humidity seems high, it should probably be about 70% r.h., and the storage period seems too short. During storage where the temperature fluctuated from the average 6 °C by ± 5 °C, 3 °C or 1 °C every 12 or 6 h. Ito and Nakamura (1985) found that fluctuating temperature had a particularly deleterious effect on the quality of shallots.

Sika kanda

Dioscoreaceae

Dioscorea hamiltonii Hook. f. Other common names include murmujja amiala, brara, tha lang ta, thakan budo, tan pawa, adavi pemdalam, karu kamda and venni kalasu. It occurs and probably originated in Southeast Asia. It is found across the Indian sub-continent from the foothills to 1400 m. It is rare in the wild but is found especially in the interior of moist deciduous forests of the Himalayas from Nepal to Bhutan, Assam, Myanmar and throughout Indochina (Kaladhar *et al.* 2008). It is found in the forests of Chittagong and Chittagong hill tracts and occasionally on slopes by forest borders, but less so on the plains (Burkill 1935). Tubers are used for the treatment of dysentery (Kaladhar *et al.* 2008) and the Chakma people use the skin and the juice of tubers as vasicatories and the leaf paste for the treatment of jaundice (Yusuf *et al.* 2009). The Chakma are a community that inhabits parts of Bangladesh, India and Myanmar. Methanolic and ethyl acetate leaf extracts from *D. hamiltonii* have shown to have good antimicrobial activity against certain organism that was tested by Kaladhar *et al.* (2008). A climber with leaves opposite and alternate up to 20 cm long, ovate or lanceolate in shape. Male flower spikes are whorled on the branches of very slender, elongate, axillary and terminal panicles. The flowers are small and globose. The fruit are capsules 2.5–3.8 cm long, membranous with parallel sides and an acute tip. Tubers are white and smooth with white flesh and grow in all directions. They are cylindrical and 30–45 cm long and up to 8 cm in diameter (Kaladhar *et al.* 2008).

Mohan and Kalidass (2010) gave the following analysis of tubers: 78.73% moisture, 4.37 ± 0.09 crude protein, 10.24 ± 0.22 crude lipid, 4.15 ± 0.03 crude fibre, 8.7 ± 0.09 ash, 72.53 N free extractives, $1670.44 \text{ g } 100 \text{ g}^{-1}$ calorific value (kJ 100 g^{-1} dry matter), 12.35 ± 0.03 starch, 11.76 ± 0.12 niacin and 30.16 ± 0.12 ascorbic acid g 100 g^{-1} . They also gave *in vitro* protein digestibility as 5.86% and *in vitro* starch digestibility as 66.30%. Anti-nutritional factors identified by Mohan and Kalidass (2010) were total free phenolics $0.27 \pm 0.05 \text{ g } 100 \text{ g}^{-1}$, tannins $0.02 \pm 0.01 \text{ g } 100 \text{ g}^{-1}$, hydrogen cyanide 0.04 ± 0.02 , total oxalate $0.28 \pm 0.09 \text{ g } 100 \text{ g}^{-1}$, amylase inhibitor 1.54 AIU mg^{-1} soluble starch and trypsin inhibitor 12.6 TIU mg^{-1} protein.

Snake gourd

Cucurbitaceae

Trichosanthes cucumerina L. is synonymous with *T. anguina* L. It is native to tropical Asian and occurs wild from India to Australia and has long been cultivated in south Asia and the Far East. It is a monoecious climbing annual with a slender furrowed stem. The edible portion is the fruit, which is a pale green to white pepo, up to 150 cm long, very slender in shape, sculptured with flesh containing many brownish coloured seeds. They are harvested when they reach an acceptable size, but before they are over-matured otherwise the flesh becomes bitter and fibrous. Refrigerated storage recommendations were 18.3–21.1 °C and 85–90% r.h. for 2 weeks (Pantastico 1975) and 16–17 °C and 85–90% r.h. for 10–14 days (Tindall 1983).

Soronda kanda

Dioscoreaceae

Dioscorea glabra Roxburgh and it is also referred to as *D. glabra* var. *longifolia* Prain & Burkill, *D. hongkongense* Uline ex R.Knuth and *D. nummularia* Roxburgh. Other common names include guang ye shu yu and luntak. Maneenoon *et al.* (2008) reported that *Dioscorea* is the main source of carbohydrate for the Sakai tribe at Banthad Range in Thailand. They found 15 species of *Dioscorea*, one of them was *D. glabra*, 13 are consumed by the Sakai the remaining

two were inedible. It was also reported to be growing wild and cultivated in Orissa in India (Behera *et al.* 2009). The tubers are edible but they become gluey when cooked. However, they are a cheap source of carbohydrates. They are mostly found in wild state and are sometimes poisonous, but a few are regularly cultivated for their tubers. From planting to the first leaf senescence was 120 days and the time to tuber initiation was 74 days. The growth period of the tuber was 192 days (Behera *et al.* 2009).

A climber with stems twining to the right. They do not produce bulbils. Tubers develop from short, thick rhizomes deeply in the ground. They are corky, pale yellow of brown coloured, formed singly or in clusters and are cylindrical with white edible flesh that turns yellow on drying. The depth of formation of the tubers was found to be 35 cm, the length of tuber 34–45 cm and their diameter 2.9–3.1 cm. The tubers can be formed both below and above ground and there was 3.8–4.4 of tubers per plant (Behera *et al.* 2009). Maneenoon *et al.* (2008) gave the following analysis of the tubers: moisture 66.62 g, carbohydrate 29.65 g, protein 1.60 g, fat 0.22 g, ash 0.79 g and fibre 1.12 g 100 g⁻¹. Energy was 126.98 kcal.

Sorrel

Polygonaceae

Rumex acetosa, *R. scutatus*. Other common names include French sorrel, acid sorrel, cigreto, field sorrel, kemekulagi, red sorrel and sheep's sorrel. It is commonly grown in both Europe and North America. It is a perennial plant that grows up to 100 cm tall with a deep taproot. The leaves are fleshy, green and long with a fringed cone at the base and are harvested when young and used in salads and medicine. It has greenish flowers and a triangular, brown to black fruit. Sorrel leaves contain 0.3% oxalic acid and 7–15% tannins (McGuffin *et al.* 1997).

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and packaging in sealed PE-lined cartons. They also found that chlorophyll degradation was delayed effectively when exposed to 5% CO₂ in air in a flow-through system. They also studied freshly harvested sorrel under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in sealed

polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay. However, sealed film packaging was applicable only if the temperature during transit and storage was well controlled otherwise perforated polyethylene was better.

Spinach

Chenopodiaceae

Spinaca oleraceae L. It is native to south western Asia and is widely cultivated in temperate climates but cannot be grown in the lowland tropics (Purseglove 1972). It is an annual whose edible part is the leaves. It produces flower stalks up to about 60 cm high with small green flowers. The round-seeded types, or summer spinach, are shown in spring or summer and leaves are harvested when they are large enough. Another type is the prickly seeded spinach or winter spinach that are shown in summer and harvested from autumn through to the following spring. They are more spreading plants with triangular-shaped leaves. New Zealand spinach (*Tetragonia expansa*), spinach beet (*Beta vulgaris*) Seakake beet or chard (also *B. vulgaris*) Orache (*Atriplex hortensis*) and amaranthus spinach (*Amaranthus* spp.) are also used as spinach as well as a range of Chinese leaf vegetables. See also Asian spinach (*Brassica* spp., *Chrysanthemum* spp., *Ipomea* spp.) and Indian Spinach (*Basella alba*). The chemical content was given by USDA Nutrient Database (2012a) in Table 117.

Harvesting and handling

The leaves are harvested when they are young and tender, but before the flower stalks begin to develop. They are usually cut from the taproot and yellowing, dead and diseased leaves are removed before bunching for the market. Wardlaw (1937) recommended top icing using crushed ice made from fresh clean water. Approximately 1 kg of ice was recommended for 1.8 kg of leaves (Suslow and Cantwell 1999).

Postharvest physiology

The ethylene production rate for fresh spinach was less than 0.1 µl kg⁻¹ h⁻¹ at 20 °C (Suslow and Cantwell 1999). Spinach is very sensitive to ethylene

Table 117 The composition of spinach leaves for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	91.40 g	Thiamine	0.078 mg
Energy	23 kcal	Riboflavin	0.189 mg
Protein	2.86 g	Niacin	0.724 mg
Total lipid (fat)	0.39 g	Vitamin B-6	0.195 mg
Carbohydrate, by difference	3.63 g	Folate	194 µg_DFE
Total dietary fibre	2.2 g	Vitamin B-12	0.00 µg
Sugars, total	0.42 g	Vitamin A	469 µg_RAE
Calcium	99 mg	Vitamin A	9377 IU
Iron	2.71 mg	Vitamin E (α-tocopherol)	2.03 mg
Magnesium	79 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	49 mg	Vitamin D	0 IU
Potassium	558 mg	Vitamin K (phylloquinone)	482.9 µg
Sodium	79 mg	Fatty acids, total saturated	0.063 g
Zinc	0.53 mg	Fatty acids, total monounsaturated	0.010 g
Total ascorbic acid	28.1 mg	Fatty acids, total polyunsaturated	0.165 g

which causes rapid yellowing (Suslow and Cantwell 1999). Hodges and Forney (2000) found that spinach stored at 10 °C in air plus 10 µl L⁻¹ ethylene showed a rapid decrease in levels of almost all the antioxidants assessed which indicated rapid senescence. Inaba *et al.* (1989) found that there was no response in respiration rate to ethylene at 100 µl L⁻¹ for 24 h at any temperature between 5 and 35 °C. The respiration rate was given as 19–22 CO₂ kg⁻¹ h⁻¹ at 0 °C, 32–58 CO₂ kg⁻¹ h⁻¹ at 5 °C, 82–138 CO₂ kg⁻¹ h⁻¹ at 10 °C, 134–223 CO₂ kg⁻¹ h⁻¹ at 15 °C and 172–287 CO₂ kg⁻¹ h⁻¹ at 20 °C (Suslow and Cantwell 1999). Reduced O₂ levels had very little effect on respiration rate and there was some indication that it might increase it, which is difficult to explain (Table 118). Grozeff *et al.* (2010) found that treatment with 0.1 or 1.0 µl L⁻¹ 1-MCP inhibited ethylene sensitivity which was successfully used to retain their quality and chlorophyll content in storage at 23 °C for 6 days compared to those not treated.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for only about 1 day. They will freeze at about

Table 118 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Prickly True spinach (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	50	70	80	120	150
In 3% O ₂	51	–	87	–	137

–1.0 to –0.8 °C (Wright 1942) or –0.50 to –0.28 °C (Weichmann 1987) and storage below 0 °C can result in freezing which results in water-soaked tissue and decay (Suslow and Cantwell 1999). Refrigerated storage recommendations are as follows:

- –0.5 to 1 °C and 90–95% r.h. for 1–2 weeks (Wardlaw 1937, Anonymous 1967, 1968, Phillips and Armstrong 1967, Lutz and Hardenburg 1968);
- 0 °C and 90–95% r.h. for 8 days (Mercantilia 1989);
- 2 °C for 6 days (Mercantilia 1989);
- 8 °C for 3 days (Mercantilia 1989);
- 0 °C and 95–100% r.h. for 10–14 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 1–2 weeks (Snowdon 1991);
- 0 °C and 95–98% r.h. for about 2 weeks (Suslow and Cantwell 1999).

Controlled atmosphere storage

Young, tender spinach leaves 8–10 cm long and leaves harvested at the traditional length of more than 15 cm long were stored at 7.5 °C in 5% O₂ + 10% CO₂. The initial appearance was maintained for up to 12 days but carotenoids were present in a lower concentration than those that had been stored in air at 7.5 °C. Chlorophyll levels in both maturities of leaves were highest after storage in 5% O₂ + 20% CO₂ but leaves showed rapid deterioration in visual quality even more than those stored in air (Martinez-Damian and Trejo 2002). Storage in air at 2 °C prevented a reduction in ascorbic acid content and L-ascorbate peroxidase activity. Ascorbic acid content, L-ascorbate peroxidase activity and yellowing decreased rapidly in air at 25 °C. Storage at 10 °C in 2% O₂ + 3 or 10% CO₂ controlled enzyme activity and contributed to the preservation of ascorbic acid and L-ascorbate peroxidase activity (Mizukami *et al.* 2003). At 10 °C for 35 days Hodges and Forney (2000) found no differences in severity of senescence between leaves stored

in air or in 10% CO₂ + 0.8% O₂ + 89.2% nitrogen. Wardlaw (1937) found that storage in high concentrations of CO₂ could damage the tips of leaves but Hardenburg *et al.* (1990) reported that storage in 10–40% CO₂ + 10% O₂ retarded yellowing. Another detrimental effect associated with high CO₂ was the production of off-flavours (McGill *et al.* 1966). Other storage recommendations were as follows:

- 5 °C with 10% CO₂ retarded leaf yellowing (Pantastico 1975);
- 0–5 °C with 10–20% CO₂ and 21% O₂ which had a fair effect but was of no commercial use (Kader 1985);
- 0–5 °C with 5–10% CO₂ and 7–10% O₂, which had only a slight effect (Saltveit 1989);
- 10–40% CO₂ and 10% O₂ retarded yellowing (Hardenburg *et al.* 1990);
- 10–20% CO₂ and 21% O₂ (SeaLand 1991).

Modified atmosphere packaging

When pre-packed in plastic bags the objective should be to achieve 1–3% O₂ and 8–10% CO₂ (Suslow and Cantwell 1999). However, other workers have observed excessive decay and off-odours in MA packaged spinach unless the bags were perforated. The type and permeability of film affected off-odour development but did not influence visual sensory attributes or chlorophyll retention (Piagentini *et al.* 2002). They recommended monooriented PP or LDPE bags for storage of fresh-cut Hybrid 424.

Hypobaric storage

Bangerth (1973) found that in storage at 3 °C and 95% r.h. with 75 mm Hg retained their green colour, vitamin C and total protein content for almost 7 weeks.

Diseases

Bacterial soft rots, primarily caused by *Erwinia* and *Pseudomonas*, are the most common types of postharvest decay (Suslow and Cantwell 1999). Escalona *et al.* (2010) reported that the use of double-sided UV-C radiation at 2.4–24 kJ m⁻² was effective in reducing initial microbial counts of the tested bacteria types and psychrotrophic and Enterobacteria counts and in keeping *Listeria monocytogenes* at low levels during

storage at 5 °C for 13–14 days. Treatment did not affect the sensory quality of fresh-cut baby spinach leaves.

Spring onions

Alliaceae, Liliaceae

Allium cepa L. Other common names include green onions, scallion and scallions. The edible portion is the young leaves and immature bulbs. They are immature and therefore have a high respiration rate and deteriorate quickly after harvest. The chemical content was given by USDA Nutrient Database (2012a) in Table 119. Total world production of green onions including shallots in 2010 was estimated by FAO (2012) as 3,912,739 tonnes.

Harvesting and handling

This is normally by hand and is when the bulbs are as thick or slightly thicker than the neck, which is the bottom of the leaves just above the bulb. Roots should be cut-off close to the base but taking care not to damage the stem plate. They should be cooled within 3 or 4 h of harvesting. Hydrocooling was the most

Table 119 The composition of spring onions for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.83 g	Thiamine	0.055 mg
Energy	32 kcal	Riboflavin	0.080 mg
Protein	1.83 g	Niacin	0.525 mg
Total lipid (fat)	0.19 g	Vitamin B-6	0.061 mg
Carbohydrate, by difference	7.34 g	Folate	64 µg_DFE
Total dietary fibre	2.6 g	Vitamin B-12	0.00 µg
Sugars, total	2.33 g	Vitamin A	50 µg_RAE
Calcium	72 mg	Vitamin A	997 IU
Iron	1.48 mg	Vitamin E (α-tocopherol)	0.55 mg
Magnesium	20 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	37 mg	Vitamin D	0 IU
Potassium	276 mg	Vitamin K (phylloquinone)	207.0 µg
Sodium	16 mg	Fatty acids, total saturated	0.032 g
Zinc	0.39 mg	Fatty acids, total monounsaturated	0.027 g
Total ascorbic acid	18.8 mg	Fatty acids, total polyunsaturated	0.074 g

suitable, vacuum cooling and forced air cooling with high humidity were also suitable and air cooling in a conventional cold store was less suitable (MAFF n.d.). Top icing was also effective. Barger (1963) found that after 25–30 min of vacuum cooling at 4.0–4.6 mm Hg with a condenser temperature of -1.7 to 0°C the green onions temperature fell to 1°C from 20 to 22.2°C but this is an expensive method.

Storage

Thompson (1972b) found that in Jamaica scallions lost 14% in weight during the first day of marketing at ambient temperature of about 28°C and 71% r.h. If kept at too high a humidity they become discoloured and mouldy. Refrigerated storage recommendations were as follows:

- 0°C and 90–95% r.h. for 2 weeks (Anonymous 1967);
- 0°C and 95–98% r.h. (Shipway 1968);
- 0°C and 90–95% r.h. for a few days (Anonymous 1968, Hardenburg *et al.* 1990);
- 0°C and 95–100% r.h. (SeaLand 1991);
- $0-1^{\circ}\text{C}$ and 95–100% r.h. for 1–3 weeks (Snowdon 1991);
- $0-1^{\circ}\text{C}$ and 95–100% r.h. for 1–3 weeks (Snowdon 1991).

Controlled atmosphere storage

The following were recommended:

- $0-5^{\circ}\text{C}$ with 10–20% CO_2 and 1–2% O_2 for green onions, but it had only a fair effect and was of limited commercial use (Kader 1985);
- $0-5^{\circ}\text{C}$ with 0–5% CO_2 and 2–3% O_2 that had only a slight effect (Saltveit 1989);
- 5% CO_2 with 1% O_2 0°C for 6–8 weeks (Hardenburg *et al.* 1990);
- 10–20% CO_2 with 2–4% O_2 (SeaLand 1991).

Modified atmosphere packaging

Thompson (1972b) found that bundles of scallions packed in polyethylene film bags, with or without holes, lost little weight during marketing at 28°C , but soon became discoloured and had mould growth and were therefore unsuitable. Weight loss was reduced to only $0.2\text{ g } 100\text{ g}^{-1}\text{ day}^{-1}$ by marketing the in 250 g lots

in polyethylene bags but fungal growth was observed in 4 days. Where the bags were perforated the rate of weight loss was doubled, but still low, and fungal growth was observed after 6 days.

Hypobaric storage

Burg (2004) reported that at $0-3^{\circ}\text{C}$ they could be stored for almost 3 weeks in 50–60 mm Hg compared to less than 6 days in atmospheric pressure. Also that storage in 100–150 mm Hg had only a slight beneficial effect compared to atmospheric pressure. McKewen and Loughheed (1981) reported better chlorophyll retention in storage at 1°C in 55–60 mm Hg than in atmospheric pressure or controlled atmosphere storage. Ward (1975) found no benefit in storage in 70 mm Hg compared to storage in atmospheric pressure.

Squash, marrow

Cucurbitaceae

Cucurbita spp. *Cucurbita pepo* L. is a highly polymorphic species and confusion exists with their common names. See also the section on Pumpkin. USDA, NRCS (2012c) gave the following botanical names for field pumpkin: *C. pepo* L., *C. pepo* L. var. *medullosa* Alef., *C. pepo* L. var. *ovifera* (L.) Harz., *C. pepo* L. var. *condensa* L.H. Bailey, *C. pepo* L. var. *melo pepo* (L.) Harz and *C. pepo* L. var. *pepo*. For ozark melon they gave *C. pepo* L. var. *ozarkana* D. Decker and for Texas gourd they gave *C. pepo* L. var. *texana* (Scheele) D. Decker. Some authorities recognise three edible varieties:

- *C. pepo* var. *medullosa* Alef., which is the vegetable marrow that produces fruit that are fine grained with mild flavoured flesh often pale green in colour and with a hard skin or shell.
- *C. pepo* var. *melo pepo* Alef. See the section on Courgettes.
- *C. pepo* var. *pepo* Alef., which is the field pumpkin or wild pumpkin.

They originated in the Americas where it has been found on archaeological sites with the oldest being in Mexico dating 7000 to 5500 BCE. It was distributed over northern Mexico and south western

USA and possibly as far as the eastern seaboard in pre-Colombian times. Both *C. pepo* var. *pepo* and *C. texana* Grey (*C. pepo* L. var. *texana*) originated in Texas (Purseglove 1972). It is an annual monoecious vine or occasionally a bush. The stems and leaves have speculate bristles. The fruit has a hard sharply angular grooved peduncle and can have either a hard or soft shell that is often dull coloured. The flesh is white to dark yellow and course grained with seeds that are off white to tan in colour separating cleanly from the pulp (Purseglove 1972). The chemical content was given by USDA Nutrient Database (2012a) in Table 120.

Harvesting

They are harvested when fully mature which is usually judged from experience related to their size and gently pressing the skin to assess whether they are beginning to soften. Harvey *et al.* (1997) found that starch and dry matter did not accumulate significantly after 40 days from flowering. They also found that skin hardness and heat accumulation levels were the most effective means of estimating the optimum harvest date. Heat units should be between 240 and 300 growing degree days (base temperature 8 °C) from flowering. When fruits of the cultivar Delica were left for longer on the vine the

Table 120 The composition of *Cucurbita pepo* fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Summer, crookneck and straightneck	Summer, scallop	Summer, zucchini includes skin	Winter, acorn	Winter, butternut	Winter, hubbard	Winter, spaghetti
Water (g)	94.28	94.18	94.79	87.78	86.41	88.00	91.60
Energy (kcal)	19	18	17	40	45	40	31
Protein (g)	1.01	1.20	1.21	0.80	1.00	2.00	0.64
Total lipid (fat) (g)	0.27	0.20	0.32	0.10	0.10	0.50	0.57
Carbohydrate, by difference (g)	3.88	3.84	3.11	10.42	11.69	8.70	6.91
Total dietary fibre (g)	1.0	1.2	1.0	1.5	2.0	3.9	1.5
Sugars, total (g)	3.53	2.39	2.50	—	2.20	3.95	2.76
Calcium (mg)	21	19	16	33	48	14	23
Iron (mg)	0.44	0.40	0.37	0.70	0.70	0.40	0.31
Magnesium (mg)	20	23	18	32	34	19	12
Phosphorus (mg)	32	36	38	36	33	21	12
Potassium (mg)	222	182	261	347	352	320	108
Sodium (mg)	2	1	8	3	4	7	17
Zinc (mg)	0.29	0.29	0.32	0.13	0.15	0.13	0.19
Total ascorbic acid (mg)	19.3	18.0	17.9	11.0	21.0	11.0	2.1
Thiamine (mg)	0.051	0.070	0.045	0.140	0.100	0.070	0.037
Riboflavin (mg)	0.041	0.030	0.094	0.010	0.020	0.040	0.018
Niacin (mg)	0.448	0.600	0.451	0.700	1.200	0.500	0.950
Vitamin B-6 (mg)	0.104	0.109	0.163	0.154	0.154	0.154	0.101
Folate (µg_DFE)	19	30	24	17	27	16	12
Vitamin B-12 (µg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vitamin A (µg_RAE)	8	11	10	18	532	68	6
Vitamin A (IU)	150	217	200	367	10,630	1367	120
Vitamin E (α-tocopherol) (mg)	0.13	0.13	0.12	—	1.44	0.16	0.13
Vitamin D (D2 + D3) (µg)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vitamin K (phyloquinone) (µg)	3.2	3.3	4.3		1.1	1.3	0.9
Fatty acids, total saturated (g)	0.093	0.041	0.084	0.021	0.021	0.103	0.117
Fatty acids, total monounsaturated (g)	0.013	0.015	0.011	0.007	0.007	0.037	0.042
Fatty acids, total polyunsaturated (g)	0.082	0.084	0.091	0.042	0.042	0.210	0.239

skin hardened, the flesh became redder, dry matter increased then decreased, the soluble solids and sucrose content increased but sensory properties improved.

Penetrometers have been tested to measure firmness. Penetrometer readings increased as flesh colour and juice soluble solids increased. Harvey *et al.* (1997) showed that the earliest time to harvest fruits to ensure an acceptable level of sensory quality after simulated refrigerated shipment conditions was at a skin penetrometer measurement of 7 kg force. However, penetrometers will damage the fruit and make them unsuitable for marketing. An objective non-destructive technique for assessing the maturity of Buttercup squash used ballistic collision. This method was found to correlate well with destructive penetrometer measurements. However, the equipment was not robust enough for use in moving grading line processes (Harvey *et al.* 1995). Fruits harvested at an immature or early stage required a postharvest ripening period to enhance sweetness and texture and optimize other sensory quality (Harvey *et al.* 1997).

Curing

This was recommended by Phillips and Armstrong (1967) and Purseglove (1968) to harden the shell by exposure for 2 weeks at 23.9–29.4 °C, but other work claimed that curing was either ineffective or detrimental (Wardlaw 1937, Lutz and Hardenburg 1968).

Storage

Harvey *et al.* (1997) found that once harvested the flesh of the cultivar Delica continued to become redder, sucrose and soluble solids increased and starch and dry matter levels decreased. They will freeze at about –1.7 to –0.4 °C (Wright 1942) or –1.94 to –0.50 °C (Weichmann 1987). General refrigerated storage recommendations were as follows:

- 15.6–21.1 °C and less than 60% r.h. for 5 months with 7% loss per month (Platenius *et al.* 1934);
- 4.4 °C and 70% r.h. with 3% weight loss per month and a slow conversion of starch into sugar (Platenius *et al.* 1934);

- 12.8 °C for 5 months with 20% loss or 23.3 °C for 5 months with 63% loss (Wardlaw 1937);
- 12.8–15.6 °C and 70–75% r.h. for 3–6 months (Wardlaw 1937);
- 12.8–15.6 °C and 70–75% r.h. for 8–24 weeks with 4–15% loss (Pantastico 1975);
- 10–12.8 °C and low humidity for 6 months (Purse-glove 1968);
- 10–13 °C and 60–70% r.h. for 2–6 months (Snowdon 1991).

Recommendations for specific cultivars and types were as follows:

Acorn

- 10 °C and 70–75% r.h. for 5–8 weeks (Anonymous 1968, Lutz and Hardenburg 1968).

Buttercup

- 6.7–10 °C and 70–75% r.h. for 3 months (Anonymous 1968, Phillips and Armstrong 1967).

Calabaza

- 10 °C and 50–70% r.h. for 60–90 days (SeaLand 1991).

Table Cream

- 6.7–10 °C and 70–75% r.h. for 2 months (Anonymous 1968, Phillips and Armstrong 1967).

Table Queen

- 10 °C and 70–75% r.h. for 5–8 weeks (Anonymous 1968, Lutz and Hardenburg 1968). At 12.8–21.1 °C Table Queen became yellow with stringy flesh within 5 weeks (Lutz and Hardenburg 1968). Chilling injury was found in Table Queen at both 0 and 4.4 °C (Platenius *et al.* 1934).

Controlled atmosphere storage

Controlled atmosphere storage was reported to have only a slight to no effect (SeaLand 1991).

Hypobaric storage

Burg (2004) reported that storage of Yellow Crook-neck at 7.2 °C and 65, 80 or 150 mm Hg had no beneficial effects compared to storage at atmospheric

pressure. McKeown and Loughheed (1981) reported similar results for Acorn.

Sugar cane

Gramineae, Poaceae

Saccharum officinarum L. also called noble cane. Other species of sugar cane include *S. barberi* Jeswiet, *S. edule* Hassk., *S. robustum* Brandes & Jeswiet, *S. sinense* Roxb. and *S. spontaneum* L. *S. officinarum* produce thick stems and have been grown for chewing from ancient times in the Pacific islands and Southeast Asia. This practice has spread throughout the tropics wherever sugar cane is grown and an export trade had developed to European and North American countries. There are various species of *Saccharum* grown commercially for sugar extraction but the noble cane is preferred for chewing since they are relatively soft and has both a high juice and a sugar content (Purseglove 1972).

Harvesting should be when the sugar content has reached its peak and is usually 14–18 months after planting and 12 months for ratoons. Retarding the growth rate by withholding irrigation and fertilizers are used to hasten maturation (Purseglove 1972). In preparation for marketing they are normally cut into short lengths before being sold and may often be peeled. Peeling and cutting stimulated the increase of respiration rate of sugarcane by more than eight times. The shorter the sugarcane section, the more the respiration rate is increased. During storage of the cultivar Badila in China, activities of sucrose invertases and PPO increased gradually, titratable acid, alcohol and reducing sugar contents increased, while sucrose and soluble sugar contents decreased. Peeled sugarcane, combined with vacuum packaging, could be successfully stored for 20 days at 0 °C (Mao and Liu 2000).

Swamp cabbage

Convolvulaceae

Ipomoea aquatica Forsk., synonymous with *I. rep-tans* Poir., also called skunk cabbage. It is a tropical, aquatic, herbaceous, floating or trailing perennial,

Table 121 The composition of swamp cabbage (*Ipomoea aquatica*) for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.47 g	Zinc	0.18 mg
Energy	19 kcal	Total ascorbic acid	55.0 mg
Protein	2.60 g	Thiamine	0.030 mg
Total lipid (fat)	0.20 g	Riboflavin	0.100 mg
Carbohydrate, by difference	3.14 g	Niacin	0.900 mg
Total dietary fibre	2.1 g	Vitamin B-6	0.096 mg
Calcium	77 mg	Folate	57 µg_DFE
Iron	1.67 mg	Vitamin B-12	0.00 µg
Magnesium	71 mg	Vitamin A	315 µg_RAE
Phosphorus	39 mg	Vitamin A	6300 IU
Potassium	312 mg	Vitamin D (D2 + D3)	0.0 µg
Sodium	113 mg	Vitamin D	0 IU

which is cultivated in Asia for the young terminal shoots and leaves that are used as spinach. It is also used as a fodder crop (Purseglove 1972). The chemical content was given by USDA Nutrient Database (2012a) in Table 121.

Swamp taro

Araceae

Cyrtosperma chamissonis (Schott) Merr. Other common names include giant swamp taro, gallan and palauan. Hather and Weisler (2000) reported that 'Subfossil leaf fragments of Giant Swamp Taro were recovered from archaeological contexts dating as early as 1451 CE (mean date) on Henderson Island (24° 22' S, 128° 19' W), Pitcairn group a raised limestone (makatea) island isolated at the extreme margin of south eastern Polynesia and the Indo-West Pacific biotic province'. It was introduced into the Philippines, Papua New Guinea and the Pacific islands in pre-European colonization times.

Botany

It is a giant succulent herbaceous perennial plant with normally 6–8 enormous leaves up to 4 m high arising from a short subterranean stem. The base of the stem is thickened to form a corm, which can be conical, cylindrical or spherical in shape and weighs 15–25 kg although they can be as much as 100 kg

or more on 10-year-old plants (Kay 1987, Diop and Calverley 1998). Cormels are produced around the main corm, which develop into suckers some 3 years after planting. Both the corms and the cormels are eaten after cooking by boiling, steaming or roasting.

Chemistry

Kay (1987) reported analyses of tubers grown in the South Pacific as energy 598 kJ 100 g⁻¹, water 60–70%, protein 0.5–1.4%, fat 0.1–0.5%, carbohydrate 28–36%, fibre 1–1.6%, ash 1–1.9%, calcium 301–598 mg 100 g⁻¹, iron 0.9–1.4 mg 100 g⁻¹, phosphorus 28–79 mg 100 g⁻¹, thiamine 0.03–0.06 mg 100 g⁻¹, riboflavin 0.08–0.11 mg 100 g⁻¹, niacin 0.6–1.1 mg 100 g⁻¹ and ascorbic acid trace to 1 mg 100 g⁻¹. Englberger *et al.* (2008) compared frozen and dehydrated samples and found that frozen samples had a higher concentration of carotenes than dehydrated ones.

Harvesting

They can be stored in the ground and therefore harvesting can be anything between 9 months and 4 years (Bradbury and Holloway 1988) although Kay (1987) stated that they require 2–3 years of growth before harvesting. Diop and Calverley (1998) reported that it can take several years to mature but they are commonly left for 15 years or more before harvest. They are dug from the soil by hand.

Storage

Koch (1986) reported that the corm needs to be eaten within 2–3 days of harvesting, although corms can be stored in moist ground for up to 6 months. In the South Pacific they may be stored in barns, submerged in water or buried in wet sand. They can also be stored for 2–3 months in lined pits covered with stones or soil and for about 1 month at 15 °C (Bradbury and Holloway 1988). Kay (1987) stated that they are sometimes buried in a damp place and kept there for up to 6 months. Diop and Calverley (1998) reported that they may be field stored in the ground for very long periods of up to 30 years or more and has traditionally been an important emergency crop in times of natural disaster and food scarcity. It is relatively resistant to disease and pests but is susceptible to taro beetle.

Table 122 The composition of rutabaga for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.66 g	Riboflavin	0.040 mg
Energy	36 kcal	Niacin	0.700 mg
Energy	151 kJ	Pantothenic acid	0.160 mg
Protein	1.20 g	Vitamin B-6	0.100 mg
Total lipid (fat)	0.20 g	Folate, total	21 µg
Ash	0.81 g	Folic acid	0 µg
Carbohydrate, by difference	8.13 g	Choline, total	14.1 mg
Total dietary fibre	2.5 g	Vitamin B-12	0.00 µg
Sugars, total	5.60 g	Vitamin B-12, added	0.00 µg
Calcium	47 mg	Vitamin A	0 µg_RAE
Iron	0.52 mg	Vitamin A	2 IU
Magnesium	23 mg	Lycopene	0 µg
Phosphorus	58 mg	Lutein + zeaxanthin	0 µg
Potassium	337 mg	Vitamin E	0.30 mg
		(α-tocopherol)	
Sodium	20 mg	Vitamin E, added	0.00 mg
Zinc	0.34 mg	Vitamin D (D2 + D3)	0.0 µg
Copper	0.040 mg	Vitamin D	0 IU
Manganese	0.170 mg	Vitamin K	0.3 µg
		(phyloquinone)	
Selenium	0.7 µg	Fatty acids, total	0.027 g
		saturated	
Total ascorbic acid	25.0 mg	Fatty acids, total	0.025 g
Thiamine	0.090 mg	monounsaturated	
		Fatty acids, total	0.088 g
		polyunsaturated	

Swede

Brassicaceae, Cruciferae

Brassica napus L. var. *napobrassica* (L.) Rchb., synonymous with *B. napobrassica* (L.) Rchb. It is also called rutabaga. It is thought to be of comparatively recent origin, possibly in Bohemia in the 17th century, as a cross between *B. rapa* and *B. oleracea* (Harrison *et al.* 1985). It produces a swollen taproot that is joined to the tuberized stem base by the epicotyls forming a neck. This distinguished it from the turnip (*B. rapa*). Morphologically it can be distinguished by the swollen neck with the leaf base scars seen as small ridges (Harrison *et al.* 1985). The chemical content was given by USDA Nutrient Database (2012a) in Table 122.

Preharvest factors

Anonymous (2010) reported that limited nitrogen supply resulted in slow and steady growth and

improved shape, size and storability of the root. They can tolerate a limited period of temperatures as low as -3°C , however if a significant frost occurs over a period longer than 24 h, the root may freeze, develop a glazed appearance and be unsuitable for either storage or sale.

Harvesting and handling

They are particularly susceptible to bruising, especially during mechanical harvesting, which can lead to the development of rot in storage. In Canada much of the crop is harvested by hand (Peters *et al.* 2007). In the United Kingdom they can be pulled by hand, which is the traditional way that is still widely used, then put into nets or placed in potato boxes. This method ensures that the best swedes are selected and little damage is done to them, but it is labour intensive. Mechanical harvesting using adapted potato-lifting equipment requires the crop to be grown in beds to avoid wheel damage. They are then put into potato boxes or bulk trailers to transport to the packhouse. The choice of system will depend on the suitability of the soil type for harvesting the crop at the anticipated harvest date, the availability of labour, the scale of the operation and prevailing ground conditions at the time of harvest (Red Tractor 2008). In Canada harvesting in warm or wet conditions, or putting wet roots into store can make them more susceptible to postharvest diseases. Roots harvested during dry weather tend to shrivel and soften if the level of humidity is not sufficient in storage (Anonymous 2010).

Roots should be cooled as quickly as possible. Storage burn (a brown surface discolouration) can be largely controlled by rapid cooling to 0°C together with adequate air circulation (Franklin and Loughheed 1975). Holmes and Kemble (2009) recommended room cooling for rutabagas grown in the southern United States. However, hydrocooling, forced air cooling and package icing are also used.

Coatings

Coating with paraffin wax reduced weight loss but if this coating was too thick the reduced O_2 supply could result in internal breakdown (Lutz and Hardenburg 1968). Chemical dips are not approved for use on culinary swedes in the United Kingdom (Red Tractor 2008).

Table 123 Respiration rates of rutabagas at different temperatures (source: adapted from International Institute of Refrigeration)

Temperature ($^{\circ}\text{C}$)	$\text{mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$
0	4–6
5	8–12
10	9.5–19
15	20–31
20	34–40

Postharvest physiology

They produce low amounts of ethylene at less than $0.1 \mu\text{l kg}^{-1} \text{ h}^{-1}$ at 20°C , but ethylene was shown to increase respiration rate of swedes especially if it was accumulated in stores especially if they are stored with a climacteric fruit (Rhodes and Woollorton 1971). Their respiration rates are given in Table 123.

Storage

They can be stored for a few weeks after harvest, but even with temperature and humidity control, weight loss and spoilage by rots can be unacceptably high in the United Kingdom (Red Tractor 2008). Damaged roots do not store well and bruising may not be apparent until the crop has been stored for 3–4 months (Anonymous 2010). At room temperature of 20°C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 2 weeks. They will freeze at about -2.0 to -1.2°C (Wright 1942) or -1.50 to -1.06°C (Weichmann 1987). Storage at 0°C prevented sprouting but at higher storage temperatures sprouting could occur but could be prevented by treatment with maleic hydrazide (Phillips and Armstrong 1967) where this is permitted. Refrigerated storage recommendations were as follows:

- 0°C and 90–95% r.h. for 6 months (Phillips and Armstrong 1967);
- 0°C with high humidity (Franklin and Loughheed 1975);
- 4°C for 4 months (Mercantilia 1989);
- 12°C for about 7 weeks (Mercantilia 1989);
- 0°C and 90–95% r.h. for 6 months (Mercantilia 1989);
- 0.5°C and 97–98% r.h. in an ice bank store where they remained turgid, firm and with no regrowth for 34–38 weeks (Geeson *et al.* 1989);

- 2–2.5 °C and 90–95% r.h. in a conventional store but they were flaccid with root and leaf growth after 25–38 weeks (Geeson *et al.* 1989);
- 2 °C and 95% r.h. for 6 months lost 6% in weight (Cutcliffe and Anderson 1989);
- 5 °C and 90% r.h. for 6 months lost 11% in weight (Cutcliffe and Anderson 1989);
- 0 °C and 90–95% r.h. for 2–4 months (Hardenburg *et al.* 1990);
- 0 °C and 95–100% r.h. for 60–120 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 4–6 months (Snowdon 1991);
- 0 °C and at least 95% r.h. for up to 9 months in Canada (Peters *et al.* 2007);
- 3 °C for 4–6 weeks in bulk boxes in the United Kingdom (Red Tractor 2008);
- 0 °C and 98–100% r.h. for 4–6 months for rutabagas grown in the southern United States (Holmes and Kemble 2009);
- 0 °C and 95% r.h. (Anonymous 2010).

Controlled atmosphere storage

Controlled atmosphere storage had a slight to no effect on keeping quality (SeaLand 1991) but CO₂ at greater than 8% was injurious (Franklin and Loughheed 1975).

Disease

Damaged or infected roots must not be placed into storage. Peters *et al.* (2007) reported that rutabagas are particularly susceptible to bruising, especially during mechanical harvesting, which can lead to the development of rot in storage. Soil contamination of storage bins can increase the spread and severity of soft rot and *Rhizoctonia* disease in storage. Regular cleaning and disinfection of tools and storage bins prior to being used for a new crop of is important to prevent the spread of pathogenic microorganisms that may cause rots during storage (Anonymous 2010). Brown soft rot caused by *Botrytis cinerea* is a major pathogen. Mould growth typically began at sites of tissue damage and then spreads to adjacent roots creating a dense surface growth of mycelium and conidia (Geeson *et al.* 1989). Black rot or Blackleg caused by *Phoma lingam* caused restricted dry, corky, dark brown or blackish lesions with a sparse

superficial growth of white mycelium. It may develop on the fleshy roots resulting in a dry rot in storage. Lesions can occur at both cut surfaces, where discoloration frequently spread into the vascular tissue, and as small craters on undamaged skin (Geeson *et al.* 1989, Anonymous 2010). *Fusarium avenaceum* was identified infecting some 80% of the rutabaga stored by one grower in Canada (Peters *et al.* 2007). Anonymous (2010) reported that infection with *Rhizoctonia solani* might occur in the field or during storage. Bacterial soft rot caused by *Erwinia carotovora* has also been associated with postharvest deterioration of roots during storage.

Sweetcorn, babycorn

Poaceae

Zea mays L. var. *rugosa* Bonaf. or *Z. mays* var. *saccharata*. *Z. mays* is an annual grass that originated in Mexico and the edible portion is the caryopsis commonly called the kernel or grain, which are borne on a modified spike that together form the ear or cob. They are formed in a leaf axil. Traditional varieties are su1 (sugary1) mutants that contain about twice the sugar (primarily sucrose) content of field corn, as well as 8–10 times higher water-soluble polysaccharide. The latter imparts a creamy consistency to su1 sweetcorn. Other mutants with increased sugar content have more recently been used, primarily sh2 (shrunk 2), which has at least double again the sugar content of su1, but almost no water-soluble polysaccharide. These newer varieties are referred to as *supersweet* and have become the dominant type in all major US sweetcorn production regions. The high initial sugar content, coupled with inhibited starch synthesis in sh2 varieties, doubles the potential postharvest life of sweetcorn. However, all supersweet varieties remain extremely perishable (Brecht 2002b).

Sweetness is the most important factor in judging acceptability followed by tenderness, juiciness and colour (Splitter and Shipe 1972). The chemical content was given by USDA Nutrient Database (2012a) in Table 124.

Harvesting

Partially mature cobs are marketed as sweetcorn while even more immature, and thus smaller cobs, are

Table 124 The composition of sweetcorn for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	76.05 g	Thiamine	0.155 mg
Energy	86 kcal	Riboflavin	0.055 mg
Protein	3.27 g	Niacin	1.770 mg
Total lipid (fat)	1.35 g	Vitamin B-6	0.093 mg
Carbohydrate, by difference	18.70 g	Folate	42 µg_DFE
Total dietary fibre	2.0 g	Vitamin B-12	0.00 µg
Sugars, total	6.26 g	Vitamin A	9 µg_RAE
Calcium	2 mg	Vitamin A	187 IU
Iron	0.52 mg	Vitamin E (α-tocopherol)	0.07 mg
Magnesium	37 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	89 mg	Vitamin D	0 IU
Potassium	270 mg	Vitamin K (phylloquinone)	0.3 µg
Sodium	15 mg	Fatty acids, total saturated	0.325 g
Zinc	0.46 mg	Fatty acids, total monounsaturated	0.432 g
Total ascorbic acid	6.8 mg	Fatty acids, total polyunsaturated	0.487 g

marketed as babycorn. For several cultivars studied in the United States the highest level of soluble solids occurred some 15 days after pollination (Splitter and Shipe 1972). There are several methods of determining harvest maturity including kernel size, shear strength, percentage pericarp, succulometer level, moisture content, sugar content and organoleptic acceptability (Khalil 1971). All these methods are destructive and in practice the experienced harvester easily assesses maturity by the degree of browning of the silks, which are green on emergence, then turn red and finally brown. This is usually coupled with the feel of the pod and if still in doubt the outer scale is drawn back to observe the kernel colour, this becomes a deeper yellow as maturity proceeds.

Pre-cooling

Sugar is converted into starch and the kernels become tougher after harvest. The rate at which these processes take place depends on temperature. Forced air cooling with high humidity was the most suitable, vacuum cooling was also suitable and air cooling in a conventional cold store and hydrocooling were less suitable (MAFF n.d.). Where vacuum cooling is used it must be first wetted (and top-iced after cooling) to

minimize water loss from husks and kernels (Stewart and Barger 1960). Crated sweetcorn can be vacuum cooled from about 30 to 5 °C in 30 min (Brecht 2002b). Vigneault *et al.* (2007) found that immersion in flowing water and perpendicular orientation of corn cobs significantly reduced the cooling time. Talbot *et al.* (1991) reported the use of hydrocooling in the United States and found that bulk sweetcorn took about 60 min to cool from 30 to 5 °C in a well-managed hydrocooler, while crated sweetcorn took about 80 min. Sweetcorn is a low acid vegetable and once wet it would be difficult to dry and might lead to bacterial growth that could cause rotting. This limits the use of hydrocooling. Vigneault *et al.* (2007) concluded that sanitation of water was essential with hydrocooling in order to avoid the contamination by spoilage organisms. However, cobs were cooled with ice fragments in an insulated box immediately after harvest and stored in a warehouse at temperature of 0–20 °C for 15 days by Kim *et al.* (1997). The total sugar loss during storage was lowest in cobs when they were cooled, compared with none cooled cobs stored at room temperature of 25–30 °C or in the low-temperature warehouse. No mention was made of increased rotting.

Respiration

Low O₂ in the store atmosphere was shown to reduce their respiration rate particularly at the higher temperature (Table 125). At 0 °C the respiration rate was given by Brecht (2002b) as 30–51 at 0 °C, 43–83 at 5 °C, 90–120 at 10 °C, 42–175 at 15 °C, 210–311 at 20 °C and 282–435 mg CO₂ kg⁻¹ h⁻¹ at 25 °C.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that both sweetcorn and babycorn could be kept for only about 1–2 days. Cobs from three Supersweet cultivars incorporating

Table 125 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of sweetcorn (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	31	55	90	142	210
In 3% O ₂	27	–	60	–	120

the *sh2* gene were given consistently higher panel test ratings for sweetness, flavour and overall quality and then normal sugary or sugary enhanced cultivars directly after harvest and throughout 24 days of storage in an ice bank at 0.5 °C and 97% r.h. (Geeson *et al.* 1991). Textural ratings showed no obvious differences between cultivars and showed relatively little change during storage (Geeson *et al.* 1991). Their freezing point was given as -0.94 to -0.61 °C (Weichmann 1987). Refrigerated storage recommendations are as follows:

- -0.6 to 0 °C and 90–95% r.h. for 1–4 weeks with considerable loss of sugar (Wardlaw 1937);
- 0 °C and 90–95% r.h. for 8 days (Phillips and Armstrong 1967);
- -0.5 to 0 °C and 85–90% r.h. for 4–8 days (Anonymous 1967);
- 0 °C and 90–95% r.h. for a few days (Lutz and Hardenburg 1968);
- 0.6–1.7 °C and 90–95% r.h. for 1 week with 3.2% loss (Pantastico 1975);
- 1 °C and 90–95% r.h. for up to 8 days (Tindall 1983);
- 4 °C for up to 5 days (Tindall 1983);
- 10 °C for about 2 days (Tindall 1983);
- 0 °C and 90% r.h. for 4–8 days for both sweetcorn and babycorn (Mercantilia 1989);
- 0 °C and 90–95% r.h. for 4–6 days (SeaLand 1991);
- 0 °C and 90–95% r.h. for 4–8 days for babycorn (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 4–8 days (Snowdon 1991).

Controlled atmosphere storage

Controlled atmosphere storage has shown that cobs may be injured in atmospheres containing more than 20% CO₂ or less than 2% O₂, but in an atmosphere of 2% O₂ the sucrose content remained higher than those stored in air (Hardenburg *et al.* 1990). SeaLand (1991) recommended 10–20% CO₂ with 2–4% O₂. Storage in high CO₂ retarded conversion of starch into sugar (Wardlaw 1937). Kader (1985) recommended 0–5 °C with 10–20% CO₂ and 2–4% O₂ which had a good effect but was of no commercial use. Saltveit (1989) recommended 0–5 °C with 5–10% CO₂ and 2–4% O₂ which had only a slight effect. Fellows (1988) recommended a maximum of

20% CO₂ and Inaba *et al.* (1989) recommended 80% CO₂ + 20% air at 15 or 25 °C which reduced their respiration rate. CA has been shown to preserve sugar content for example 5 °C in 2% O₂ + 15% CO₂ for 14 days preserved the highest sugar level and reduced deterioration in visual quality (Riad and Brecht 2003). Ryall and Lipton (1979) also reported that storage in 5–10% CO₂ retarded sugar loss while 10% caused injury. CA of 2% O₂ + 10 or 20% CO₂ reduced respiration rate and maintained higher sugar levels during 10 days at 1 °C of fresh-cut sweetcorn (Riad and Brecht 2001). Storage in high CO₂ retarded conversion of starch into sugar (Wardlaw 1937) but cobs may be injured with more than 20% CO₂ or less than 2% O₂. Brash *et al.* (1992) stored cobs of the cultivar Honey 'n' Pearl at 0 °C in 2.5% O₂ or levels of CO₂ in the range 5–15% for 3–4 weeks followed by 3 days shelf life assessment at 15 °C in simulated sea freight export trials in New Zealand. 2.5% O₂ + 6–10% CO₂ ensured cobs retained sweetness and husk leaves stayed greener for longer during shelf life compared to those that had been stored in air. Controlled atmosphere storage for 3 weeks also reduced insect numbers. The use of controlled atmosphere storage to control insect pests on sweetcorn harvested in New Zealand was studied by Carpenter (1993) who concluded that storage at 0–1 °C alone was as effective as treatment with CA.

Modified atmosphere packaging

The best packaging proved to be non-perforated film or film with the minimum perforation that is one 0.4 mm hole per 6.5 cm². Cobs packed in PP film with no perforations showed a reduced rate of toughening, weight loss and loss of sweetness, but they tended to develop off-odours. Packing cobs with the sheath still attached but partly cut away to reveal the seeds below was the best treatment from both the storage and presentational aspects (Othieno and Thompson 1993, Othieno *et al.* 1993). Manleitner *et al.* (2003) found that changes of carbohydrate composition of the cultivar Tasty Gold were influenced by the permeability of the films during 20 days of storage at 5 °C. Sweetcorn in films with low permeability maintained their carbohydrate content during storage but had low sucrose after subsequent shelf life of 2 days at 20 °C. Losses of sucrose during the shelf life phase were lowest in 20 µm LDPE film. Retail packages of

sweetcorn (film-wrapped trays containing a pair of trimmed cobs) were stored at 2 °C within additional plastic liners by Rodov *et al.* (2000). The atmosphere generated in these nested packages was within the recommended range 5–10% CO₂. Opening the liner after transfer to non-refrigerated conditions compensated for the respiration rate rise caused by elevated temperature, maintained the desirable modified atmosphere range and prevented fermentation and off-flavour development. The cobs kept for 2 weeks at 2 °C within nested packages and for 4 additional days at 20 °C combined relatively low microbial spoilage with acceptable organoleptic quality. Mineral powders are incorporated into some films that can be used sweetcorn (Industrial Material Research 1989, quoted by Abe 1990).

Hypobaric Storage

Haard and Salunkhe (1975) found that hypobaric storage could increase their storage life to 21 days from 4 to 8 days in a conventional cold storage. Burg (2004) stored the cultivar Wintergreen at 1.7 ± 1 °C at pressures over the range of 10 mm Hg to atmospheric pressure and found that their respiration rate decreased with decreasing pressure. After 7 days those stored in 20 mm Hg had the highest scores for sweetness and flavour. After 11 days those that had been stored in 50 mm Hg had the best flavour.

Diseases

Trimming ears can promote decay development on the cut kernels and other damaged tissues mainly caused by *Alternaria alternata* (Fr.) Keissler, *Fusarium moniliforme* Sheldon and *Mucor hiemalis* Wehmer (Aharoni *et al.* 1996).

Sweetpotato

Convolvulaceae

Ipomoea batatas (L.) Lam. Other common names include Louisiana yam, Spanish potato, batata and yam. It is believed to have originated in north western South America, which is the major centre of its diversity but other centres of diversity exist in sub-Saharan Africa, Papua New Guinea and Indonesia. The majority of *Ipomoea* species are native to

the Americas (Jarret and Austin 1994, Collins 1995). Kay (1987) reported that in pre-Columbian times it was cultivated in Central America, the Caribbean and parts of South America as well as Polynesia and New Zealand. It is a perennial herbaceous vine, which has considerable variation in the form and growth habit. They have twining and trailing stems that can be up to 4.5 m long. They may be of slender to moderate in thickness and have moderately to widely spaced leaves. These are the most prevalent, but types with short thick stems, short internodes and semi-erect to erect growth habits also occur (Kay 1987). The edible portion is the swollen tuber, which is part stem and part root with no morphological division between the two. The root tubers are formed by a thickening of parts of the adventitious roots close to the subterranean part of the stem or at the nodes which rest on the soil. When the tubers are stored they will eventually sprout but only in the upper part, which is the stem part. The tubers are fusiform to globular in shape with a white, brown, red or purple skin. The flesh is white or yellow in colour, but it may also be reddish.

Chemistry

The chemical composition of sweetpotato tubers varies widely according to cultivar, climatic conditions, degree of maturity and the duration of storage after harvesting. Kay (1987) quoted values for the edible portion as energy 490 kJ 100 g⁻¹, water 65–81%, carbohydrate 25–32%, protein 0.95–2.4%, fat 0.4–6.4%, fibre 0.9%, ash 0.9–1.4%, calcium 30–34 mg 100 g⁻¹, iron 0.8–1 mg 100 g⁻¹, magnesium 24 mg 100 g⁻¹, phosphorus 49 mg 100 g⁻¹, potassium 373 mg 100 g⁻¹, sodium 13 mg 100 g⁻¹, carotene trace to 12 mg 100 g⁻¹, thiamine 0.1 mg 100 g⁻¹, riboflavin 0.05–0.06 mg 100 g⁻¹, niacin 0.6–0.9 mg 100 g⁻¹ and ascorbic acid 23–25 mg 100 g⁻¹. Various phenolic compounds are present with phenolic acids being the most common. Varieties with red or purple skins or flesh also contain anthocyanins and those with orange and yellow pigmentation contain β-carotene, which besides being a precursor to vitamin A also has antioxidant activity. Simple phenolic acids, coumarins and an acidic glycoprotein are believed to be responsible for some of the antioxidant activity shown in many cultivars (Hedges and Lister 2006). They contain

Table 126 The composition of sweetpotatoes for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	77.28 g	Thiamine	0.078 mg
Energy	86 kcal	Riboflavin	0.061 mg
Protein	1.57 g	Niacin	0.557 mg
Total lipid (fat)	0.05 g	Vitamin B-6	0.209 mg
Carbohydrate, by difference	20.12 g	Folate	11 µg_DFE
Total dietary fibre	3.0 g	Vitamin B-12	0.00 µg
Sugars, total	4.18 g	Vitamin A	709 µg_RAE
Calcium	30 mg	Vitamin A	14,187 IU
Iron	0.61 mg	Vitamin E	0.26 mg
		(α-tocopherol)	
Magnesium	25 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	47 mg	Vitamin D	0 IU
Potassium	337 mg	Vitamin K	1.8 µg
		(phyloquinone)	
Sodium	55 mg	Fatty acids, total saturated	0.018 g
Zinc	0.30 mg	Fatty acids, total monounsaturated	0.001 g
Total ascorbic acid	2.4 mg	Fatty acids, total polyunsaturated	0.014 g

vitamin C, iron, potassium and calcium and the skin also contains fibre. Padda and Picha (2008) found that the skin tissue contained the highest concentration of total phenolics of up to 17.7 mg chlorogenic acid equivalent per gram of dry weight. Chlorogenic acid was the principal phenolic acid found in all sweetpotato tissues. Caffeic acid and three isomers of dicaffeoylquinic acid were also identified. The antioxidant capacity was the highest in the skin tissue with 22.9 mg Trolox equivalent per gram tissue dry weight. The toxic metabolites ipomeamarone and ipomeamaranol have been isolated from mouldy tubers. Poisoning of cattle has been reported to be associated with the incorporation of mouldy sweetpotatoes in their feed. These metabolites may occur in tubers that show only slight blemishes, insufficient to arouse suspicion that they are toxic (Wilson *et al.* 1970, Kay 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 126.

Preharvest factors

Kay (1987) reported that the pH range for optimum yield was 5.6–6.6. Kihurani *et al.* (2008) showed that growing sweetpotato in soil at the different pH levels of 4.6, 5.8 and 6.1 did not significantly influence

postharvest pathological deterioration of the roots caused by *Rhizopus oryzae* and *Botryodiplodia theobromae*.

Harvesting

Although it is a perennial it is easily propagated by stem cuttings and therefore usually re-planted each season. There are simple tests that can be used by farmers to determine when they are ready for harvest. Mature tubers have a high starch content and this can be empirically judged by cutting samples to pieces. If they dry out quickly when exposed to air they are mature (Pantastico 1975). Another test is that the sap from immature tubers rapidly turns black on exposure to air (Kay 1987). In the tropics harvest maturity is often assessed by when the leaves turn yellow and begin to die. Time after planting has also been used, but this varies between cultivars, weather and climatic conditions. They are normally harvested 3–8 months after planting. In the tropics, if grown in the wet season, the crop normally takes longer to mature than when grown as a dry season crop (Kay 1987). In trials carried out in Eritrea (Table 127) there was a large difference in optimum harvest time between seasons. At the cooler time of the year 6 months after planting gave the highest yields, but in the warmer months 5 months after planting was the optimum harvest time. This was also reflected in vine yield (which is used as animal feed). Since both tuber and vine yield were still increasing up to 6 months in the winter season it may not be the optimum harvest time; it could be 7 or 8 months.

In North America harvesting is carried out before the first frosts or just after the first light frosts. They

Table 127 Effects of planting season and harvest time on the yield of tubers and vines of sweetpotatoes grown under irrigation. (source: adapted from National Agricultural Research Institute 2005)

Harvest time after planting (months)	Winter crop (December to May)			Summer crop (May to October)		
	4	5	6	4	5	6
Tuber yield (tonnes ha ⁻¹)	3.5	11.9	35.1	35	56	52
Vine yield (tonnes ha ⁻¹)	35.7	53.0	67.6	98	100	59

Figures are means of 2 seasons and 14 cultivars.

are left in the ground for as long as possible to maximize yield, but if the tubers are affected by frost they will quickly rot during storage. Cantwell and Suslow (2001) indicated that irrigation is typically stopped 2–3 weeks before harvest so that vines begin drying before harvest.

The tubers can be harvested by digging with a fork or spade being careful not to cut or damage the tubers and then carefully pulling at the vines. However, where there is large-scale production the vines are usually cut away and the tubers harvested by ploughing out or by being dug out with combine-type harvester units. Mechanical harvesters similar to the ones used for potatoes (*Solanum tuberosum*) are also used. The methods used for harvesting have a considerable effect upon their market quality and storage life since they are very easily damaged and very susceptible to fungal rots. Unless great care is taken to avoid mechanical injury heavy losses are likely to be incurred and it is for this reason that efficient mechanical harvesters have proved difficult to design and operate effectively. However, substantial advances have been reported, including machines that dig the sweetpotatoes, detach them from the vines and deposit them in a container (Abrams *et al.* 1978, Kay 1987).

Pre-cooling is not commonly used but Holmes and Kembler (2009) recommended room cooling for sweetpotatoes grown in the southern United States.

Sprouting

Work on gibberellins and gibberellin synthesis inhibitors suggests that gibberellins are involved in the stimulation of sprouting in sweetpotatoes (Cheema *et al.* 2010). In Trinidad preharvest spraying with maleic hydrazide or treating the tubers postharvest with MENA has been reported to inhibit sprouting. MENA was applied by interleaving it with layers of paper soaked in MENA in acetone at a ratio of 40 ml 100 kg⁻¹ tubers (Kay 1987). Paton and Scriven (1989) applied NAA under reduced pressure either as a 1 g L⁻¹ solution containing a wetting agent or as a dust of 1, 10 or 100 mg g⁻¹ of talc. During storage of at least 40 days NAA applied as a solution reduced sprouting by more than 50% and when it was applied in talc the reduction in sprouting was 29%. However, in both cases there was an increase in water loss. Cheema *et al.* (2010)

showed that 20 µl L⁻¹ ethylene was effective in controlling sprouting in sweet potato over 4 weeks of storage at 25 °C. Cheema *et al.* (2013) reported that continuous exposure to 10 µl L⁻¹ ethylene, 24 h exposure to 625 nl L⁻¹ 1-MCP or dipping in 100 µl L⁻¹ aminoethoxyvinylglycine all inhibited sprout growth of two sweetpotato varieties during 4 weeks of storage at 25 °C. They also found that respiration rates were higher in the ethylene-treated roots than those that had not been treated, while both 1-MCP and AVG inhibited this increase in respiration rate.

Curing

Artschwager and Starrett (1931) first described the curing of sweetpotatoes and the processes of suberization and periderm formation are similar to those for potatoes. Walter and Schadel (1983) described the histological processes that occur during sweetpotato curing. Initially the outermost parenchyma cells at the wound site desiccate and the subtending parenchyma cells subsequently become suberized. This was followed by formation of a lignin-like wound periderm beneath the suberized layer. The process was considered adequate when the wound periderm was 3–7 cells thick. The recommended conditions for curing include

- 29–32 °C and 85–90% r.h. for 7–15 days (Lutz 1952);
- 33 °C and 95–97% r.h. (Cadiz and Bautista 1967);
- 29.4 °C and 85–90% r.h. for 4–7 days (Kushman and Wright 1969);
- 32–36 °C and 100% r.h. for 4 days (Thompson 1972b);
- 27–29.5 °C at 85–90% r.h. for 4–7 days (Kay 1987);
- 25–32 °C and greater than 90–100% r.h. for several days to 1 week (Cantwell and Suslow 2001).

Cured sweetpotatoes had a lower weight loss, less disease and their quality during subsequent storage was maintained better than those that were not cured. The interior flesh tissues accumulate antifungal compounds under curing conditions of 30 °C and 90–95% r.h. for 24 h. The presence of antifungal compounds, including 3,5-dicaffeoylquinic acid in the external tissues of sweetpotatoes, helps explain why shallow injuries can be resistant to infection (Stange *et al.* 2001). It has previously been shown that

sweetpotato cultivars differ in curing at low humidity, although this does not appear to relate to the rate of curing at high humidity. It has also been shown that there is a negative relationship between cultivar root dry matter content and efficiency of root wound healing at low humidity (Rees *et al.* 2008). They also found a relatively rapid accumulation of sugars within 24 h of healing and data from 17 cultivars confirmed the positive correlation between lignification and root sugar levels. Adequate ventilation should be supplied to sweetpotatoes during curing to prevent a build up of CO₂ that can adversely affect the process. In the tropics a simple method of curing is to keep the tubers in plastic lined boxes at ambient temperatures of 27–29 °C. Yin *et al.* (2012) treated sweetpotato discs with a nitric oxide donor to determine its effects on curing during 5 days at 28 ± 1 °C and 85% r.h. Their results indicated that nitric oxide promoted curing by ‘improving PAL activity and potentiating the antioxidative defence system’.

Postharvest physiology

Cantwell and Suslow (2001) gave the respiration rate of tubers as 7 ml CO₂ kg⁻¹ h⁻¹ at 10 °C and 0–12 ml CO₂ kg⁻¹ h⁻¹ at 15 °C for cured tubers and 15 ml CO₂ kg⁻¹ h⁻¹ at 15 °C and 27–35 ml CO₂ kg⁻¹ h⁻¹ at 25 °C for those that had not been cured. They also found that roots produce very low amounts of ethylene of about 0.1 µl kg⁻¹ h⁻¹, although much higher rates can occur after chilling, wounding and decay development. Exposure to 1–10 µl L⁻¹ of ethylene increased respiration rate from 18 to 22 µl O₂ g⁻¹ h⁻¹ (Solomos and Biale 1975). Exposure to 10 µl L⁻¹ of ethylene also increased phenolic compounds and reduced β-amylase activity that could adversely affected flavour and colour of cooked tubers (Buescher 1977). Inaba *et al.* (1989) also found that there was an increased respiration rate in response to ethylene at 100 µl L⁻¹ for 24 h in the range 20–35 °C, but the effect was much reduced at lower temperatures.

Chilling injury

Tubers will freeze at about –2.2 to –1.8 °C (Wright 1942) or –1.89 to –1.06 °C (Weichmann 1987). Chilling injury was reported to occur when the roots

were exposed to 10 °C for a few days and for shorter periods at lower temperatures (Lutz and Hardenburg 1968). Tubers that have been chilled may develop a hard texture after they have been cooked. This disorder is called hardcore and may be increased by exposure to ethylene. Timbie and Haard (1977) showed that storage of tubers at 2 °C for 3 days had more severe hardcore when exposed to 92 µl L⁻¹ ethylene than those exposed to ethylene-free air. Ceponis and Butterfield (1972), Kay (1987) and Cantwell and Suslow (2001) described symptoms of chilling injury as internal browning, internal breakdown, increased susceptibility to decay, impaired culinary quality, shrivelling and hardcore, although under certain circumstances hardcore may be reversed.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 2–3 weeks. Refrigerated storage recommendations include

- 10–12.8 °C and 80–90% r.h. for 4–6 months (Wardlaw 1937);
- 11–13 °C and 85–90% r.h. for 13 weeks (Anonymous 1967);
- 12.8–15.6 °C and 85–90% r.h. for 4–6 months with 2% weight loss per month (Lutz and Hardenburg 1968);
- 10–12.8 °C and 80–90% r.h. for 13–20 weeks with 8.5% weight loss (Pantastico 1975);
- 13–16 °C and 85–90% r.h. for up to 140 days with up to 10% losses (Tindall 1983);
- 13–16 °C and 85–90% r.h. (Kay 1987);
- 14 °C and 90% r.h. for 3–6 months (Mercantilia 1989);
- 13.3 °C and 85–90% r.h. for 90–120 days for sweetpotato (SeaLand 1991);
- 12.8 °C and 85–90% r.h. for 120–150 days for boniato (SeaLand 1991);
- 13–16 °C and 85–90% r.h. for 4–7 months (Snowdon 1991);
- 12.5–15 °C and greater than 90% for 6–10 months (Cantwell and Suslow 2001);
- 13–16 °C and 85–90% r.h. for 4–7 months for sweetpotatoes grown in the southern United States (Holmes and Kemble 2009).

Controlled atmosphere storage

Respiration rates of roots were reduced as O₂ was reduced from 21 to 3% and O₂ concentrations below 3% may result in increased respiration rates due to fermentation (Cantwell and Suslow 2001). SeaLand (1991) indicated that controlled atmosphere storage had a slight or no effect compared to storage in air. Typical storage conditions were given as 0–5 °C in 5–10% CO₂ + 2–4% O₂ by Bishop (1996). Storage in 2–3% CO₂ + 7% O₂ kept roots in better condition than those stored in air, but CO₂ levels above 10% or O₂ levels below 7% could give alcoholic or off-flavour to the roots (Pantastico 1975, Hardenburg *et al.* 1990). The cultivar Georgia Jet was stored at 15.5 °C in 85% r.h. in air or 7% O₂ + 93% N₂ atmosphere for 3 months. Controlled atmosphere storage had no effect on moisture content, β-carotene or total lipids (Charoenpong and Peng 1990). In storage for 7 days at 20 °C in air, 1% O₂ + 99% N₂ or 100% N₂ the total soluble solid content increased but weak off odours were detected in roots stored in 100% N₂. The intensity of off odours increased as the concentrations of acetaldehyde and ethanol increased in roots during storage. Ethanol concentrations were higher than those of acetaldehyde, which remained low during storage in 1% O₂ and in air, but increased greatly in roots stored in 100% N₂ (Imahori *et al.* 2007).

Disease

Postharvest diseases of sweetpotato tubers include bacterial soft rot (*Erwinia chrysanthemi*), black rot (*Ceratocystis fimbriata*), charcoal rot (*Macrophomina phaseolina*), dry rot (*Diaporthe phaseolorum* var. *bataatensis*), surface rot (*Fusarium oxysporum*) and scurf (*Monilochaetes infusans*). Java black rot (*Lasiodiplodia theobromae* synonymous with *Botryodiplodia theobromae* and *Diplodia gossypina*) is often a serious problem in the tropics since it has an optimum growth temperature of about 28 °C. Increased resistance to black rot disease was shown to occur in the presence of ethylene (Stahmann *et al.* 1966). Soft rot, ring rot or collar rot (*Rhizopus* spp.) is of considerable economic importance, since under favourable conditions it can destroy the entire tuber in a few days. Chilling injury and mechanical injury predispose sweetpotatoes to decay, especially that caused by *R. stolonifer*.

Black rot, *Fusarium* root rot, scurf and bacterial soft rot infections can occur preharvest, during harvest and postharvest. In contrast, soft rot infections tend to occur at harvest or postharvest, while charcoal rot, dry rot, surface rot and root rot occur during harvest. Harvest and postharvest pathogens are typically opportunistic pathogens that require wounds to gain entry into the root. Several species of fungi attack stored tubers and a range of chemical treatments have been shown to be successful in controlling these organisms. Storage losses due to disease, particularly soft rots, can be very substantial (Martin 1967, Steinsbauer and Kushman 1971, Moyer 1982, Kay 1987). Careful handling and curing soon after harvesting is effective in disease control. Hot water treatment has been applied to sweetpotatoes. Scriven *et al.* (1988) showed that there was a significant delay in disease development on roots that had been exposed to 90 °C for 2 s, 80 °C for 2, 4 or 10 s, 70 °C for 10 s and 40 °C for 2 min without affecting their weight loss or respiration rate. The cultivar Georgia Jet was stored for 5 months by means of disinfecting the roots with iprodione (fogging) in conjunction with the curing. At the end of the storage period, 14% of the roots had decayed following this combined treatment compared to 61% with curing alone, 60% with iprodione alone and 100% in those with neither treatment (Afeke *et al.* 1998).

Pests

Sweetpotatoes are attacked by insects, notably weevils (*Cylas formicarius*). It is the single most devastating insect pest of the crop worldwide both in the field and in storage. There are no adequate field or storage control measures, although controlled atmosphere storage may have promise (Delate and Brecht 1989). However, infested roots should not be stored. In the western hemisphere and Pacific islands the scarabee beetle (*Euscepes postfasciatus*) infects sweetpotatoes (Kay 1987).

Sweetpotato leaves

In many parts of the tropics sweetpotato vines are used as a green feed for livestock, often as silage. As an animal feed their value is comparable with that of lucerne (*Medicago sativa*). A typical analysis of the edible portion shows water 87.1%, nitrogen

0.57%, ether extract 0.67%, fibre 1.4%, ash 1.59%, calcium 81.2 mg 100 g⁻¹, iron 10.37 mg 100 g⁻¹, phosphorus 67.3 mg 100 g⁻¹, carotene 3.61 mg 100 g⁻¹, thiamine 0.06 mg 100 g⁻¹, riboflavin 0.17 mg 100 g⁻¹, niacin 0.94 mg 100 g⁻¹ and ascorbic acid 25 mg 100 g⁻¹ (Kay 1987).

Tamarillo

Solanaceae

Cyphomandra betacea (Cav.), *Solanum betaceum* (Cav.). Other common names include tree tomato and Dutch eggplant. The tamarillo is native of the Andes of Peruvian, Chile, Ecuador, Colombia and Bolivia where it is still cultivated. It has spread to other regions in subtropical areas throughout the world including South Africa, India, Hong Kong, China, the United States, Australia, and New Zealand. In the hot lowland tropics fruit setting is rare and when it occurs the fruits are small.

It is a fast-growing subtropical tree up to 5 m high (Figure 53). The fruit is ovoid-apiculate in shape and is green ripening to a reddish-orange colour (Figure 54). The fruit is up to 10 cm long and its widest part measures between 4 and 6 cm and they weigh up to 80 g. They are berries that are capped with a calyx and stem with a red-coloured smooth resistant skin. The mesocarp is solid but soft, similar to a tomato, inside of which is the watery reddish or yellow pulp divided into two lobes containing many black seeds embedded in the pulp. The mucilaginous, juicy and seedy pulp has a



Figure 53 Tree tomatoes showing growing in Colombia in 1977.



Figure 54 Tamarillo on sale in Britain in 2013.

sweet-acid taste reminiscent of the tomato. The fruit are sometimes eaten raw but usually cooked. Prohens and Nuez (2001) gave the following composition for fruit in gram per 100 f.w.: water 81–87 g, vitamin A 0.32–1.48 g, proteins 1.5–2.5 g, vitamin C 19.7–57.8 g, fat 0.05–1.28 g, calcium 3.9–11.3 g, fibre 1.4–6.0 g, magnesium 19.7–22.3 g and iron 0.4–0.94 g.

Harvesting

Harvesting is by hand when the skin has changed colour from green to red (Figure 54) and they feel slightly soft to the touch. Prohens *et al.* (1996) found that fruit that had been harvested while still green had less subsequent colour development and a lower TSS:TA ratio when ripe than fruit harvested when colour change had begun.

Postharvest physiology

They are classified as non-climacteric fruit. Ethylene production was less than 0.1 µl kg⁻¹ h⁻¹ until fruit began to senesce. Exposure of green and partially ripe fruit to ethylene resulted in increased respiration rate and accelerated red colour development. The respiration rate was given as 18–36 mg CO₂ kg⁻¹ h⁻¹ at 18–20 °C (Pratt and Reid 1976, Prohens *et al.* 1996).

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for 3–4 days. Chilling injury occurred if fruit were stored below 3 °C. Symptoms include pitting and a scald-like browning of the skin, calyx and stem. Discolouration on the peel was observed within 15 days at 0 °C (Espina and Lizana 1991). Refrigerated storage recommendations include

- 3–4.5 °C with 90–95% r.h. for 4–8 weeks plus an additional week for marketing (Harman and Patterson 1982);
- 3.5 °C 10–12 weeks with good decay control measures (Harman and Patterson 1982);
- 4 °C and 90% r.h. for 3 weeks (Mercantilia 1989);
- 3–4 °C and 90% r.h. for 6–10 weeks (Snowdon 1991);
- 3.9 °C and 85–90% r.h. for 21–70 days for Tree Tomato (SeaLand 1991);
- 0 °C and 90–95% r.h. for 28–42 days for Tamarillo (SeaLand 1991).

It is not clear what the difference is between tree tomato and tamarillo referred to in SeaLand (1991). In a comparison of storage for 35 days at either 0 or 7 °C there was more discolouration of the calyx and stem at 0 °C but more decay and softening at 7 °C (Espina and Lizana 1991).

Diseases

Fungal decay occurred on the stem and calyx in storage above 4.5 °C (Espina and Lizana 1991). The most common storage decay was due to Bitter Rot caused by *Colletotrichum acutatum* and *C. gloeosporioides*. The fungi attack fruit on the tree, but decay does not develop until fruit start to ripen or during storage. Hot water treatment at 50 °C for 8 min effectively controlled quiescent infections caused by *C. gloeosporioides* and *C. acutatum*. Hot water treatment reduced the percentage of fruit with body lesions without significantly increasing peduncle necrosis (Yearsley *et al.* 1987). They also reported that fungi colonizing damaged peduncle tissue were controlled using an imazalil dip for 1 min at 15–20 °C with 250 mg L⁻¹ a.i. Storage disorders were significantly reduced using the hot water/imazalil dip, allowing shelf life of 7 days at 20 °C after 8 weeks of storage at 3.5 °C.

Tamarind

Fabaceae, Leguminosae

Tamarindus indica L. synonymous with *T. occidentalis* Gaertn. and *T. officinalis* Hook. It is believed to be native of tropical Africa, despite its specific name, and grows wild in the Sudan and was introduced into India in ancient times and from there to Persia and Arab countries. It was well known to the ancient Egyptians and to the Greeks in the 4th century BCE. It has long been naturalized in the East Indies and the islands of the Pacific, tropical America, Bermuda, the Bahamas and the West Indies. It is now cultivated throughout Southeast Asia, Australia and the Americas. It is a commonly grown tree throughout India, mostly under rainfed conditions, and in Mexico, Guatemala, Belize and other Central American countries and in northern Brazil (Morton 1987). Tamarinds may be eaten fresh by breaking the pod and sucking the pulp or the pulp is extracted and used for curries, sauces and chutney and it is made into a refreshing beverage. The seeds can also be eaten after roasting or boiling and the flowers and young leaves can also be eaten. The pulp is dried and sold as flavouring and used in Worcester sauce.

The tamarind is a slow-growing, long-lived, tree growing up to 24–30 m with a spread of 12 m and a trunk circumference up to 7.5 m. The flowers are yellow with orange or red streaks and the fruit is a brown pod up to 15 cm long and about 2 cm wide containing several large seeds embedded in a sweet acid brown pulp. Tamarind fruit are non-climacteric. They are composed of about 30% pulp, 40% seeds and 30% shell. The colour of the pulp is due to the presence of several anthocyanins of which vitexene is the most important (Lewis and Neelakantan 1964). The fruit is a good source of calcium, phosphorous and iron, excellent source of riboflavin, thiamine and niacin, but contains only small amounts of vitamins A and C (Bueso 1980). On a fresh weight basis, mature tamarind pulp has 30–35% sugar and 12–24% TA. The pulp can have up to 10–14% acid, mainly tartaric, and up to 41% sugar. The chemical content was given by USDA Nutrient Database (2012a) in Table 128.

Harvesting

Tamarind fruit are harvested by hand when the pod turns from green to dark brown and it gives

Table 128 The composition of tamarind fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	31.40 g	Thiamine	0.428 mg
Energy	239 kcal	Riboflavin	0.152 mg
Protein	2.80 g	Niacin	1.938 mg
Total lipid (fat)	0.60 g	Vitamin B-6	0.066 mg
Carbohydrate, by difference	62.50 g	Folate	14 µg_DFE
Total dietary fibre	5.1 g	Vitamin B-12	0.00 µg
Sugars, total	57.40 g	Vitamin A	2 µg_RAE
Calcium	74 mg	Vitamin A	30 IU
Iron	2.80 mg	Vitamin E	0.10 mg
		(α-tocopherol)	
Magnesium	92 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	113 mg	Vitamin D	0 IU
Potassium	628 mg	Vitamin K	2.8 µg
		(phyllquinone)	
Sodium	28 mg	Fatty acids, total saturated	0.272 g
Zinc	0.10 mg	Fatty acids, total monounsaturated	0.181 g
Total ascorbic acid	3.5 mg	Fatty acids, total polyunsaturated	0.059 g

off a distinctive odour. Hernandez-Unzon and Lakshminarayana (1982a) found that it took about 8 months from fruit set to harvest. As pods matured the skin developed into a brown, brittle shell and the pulp turned brown or reddish-brown and the seeds became covered with a dry and sticky pulp. When fully ripe, the shells are brittle and easily broken. Fruit should be harvested when the moisture content is less than 20% to facilitate separation of the shell from the pulp. In some areas mature fruit can be left on the tree for more than 6 months after ripening, so that the moisture content will be reduced to 20% or lower, but in humid climates they may be attacked by insects, fungi and birds and should therefore be harvested before they are fully ripe. Fruit can be pulled off the peduncle or cut using scissors (Hernandez-Unzon and Lakshminarayana 1982b). Fruit for immediate processing are harvested by pulling pods away from the stalk or by shaking the branches, leaving the remaining fruit to fall naturally when ripe. Dry ripe fruits are easily cracked and the pulp and fibres separated from the broken shell. After harvest pods are spread on ground for 6–7 days. The shell, seeds and the fibrous material are removed and the pulp is collected.

Storage

SeaLand (1991) recommended 7.2 °C and 90–95% r.h. for 21–28 days. Tamarind can be stored in the shell or as a separated dry pulp. Tightly packaged pods can be stored at about 20 °C for several weeks. The pulp of mature tamarind is commonly compressed and packed in palm leaf mats or plastic bags. It can be stored at 20 °C for a significant length of time when processed into a paste or refrigerated for up to 6 months. During storage, the dry, dark-brown pulp becomes soft, sticky, and almost black. The pulp can be stored for a longer period after drying or steaming. The pulp can be stored for up to 12 months after properly drying in the sun because the TSS:TA and the low water content contribute to a long storage life (Hernandez-Unzon and Lakshminarayana 1982b).

Tannia

Araceae

Other common names include badoo, new cocoyam, nut eddoe, tanier, tannier, tania, tannia and yautia. Kay (1987) reported that a number of edible species of *Xanthosoma* Schott have been recognized including *X. sagittifolium* (L.) Schott that is by far the most widely grown. The USDA (2012d, 2012e) database gave the following species:

- *X. atrovirens* K. Koch & Bouché with the common name Yautia Amarilla. It has yellow tubers and is favoured in Puerto Rico and Dominica
- *X. brasiliense* (Desf.) Engl. with the common name Tahitian Spinach. It is a small species cultivated solely for its edible leaves
- *X. caracu* K. Koch & Bouché with the common name Yautia Horqueta
- *X. helleborifolium* (Jacq.) Schott with the common name Belembe Silvestre
- *X. robustum* Schott with the common name Capote
- *X. roseum* Schott with the common name Rosy Malanga
- *X. sagittifolium* (L.) Schott with the common name Arrowleaf Elephant's Ear
- *X. undipes* (K. Koch) K. Koch with the common name Tall Elephant's Ear
- *X. jacquinii* Schott
- *X. violaceum* Schott with the common name Purple Stem Taro. It is a large plant grown occasionally

in the Pacific islands but reportedly of little value for food.

- *X. nigrum* (Vell.) Stellfeld.

Xanthosoma is native to tropical America and was cultivated in tropical Central and South America from ancient times. In the 19th century it was widely cultivated throughout the tropical world. It is now cultivated in tropical America, the Caribbean, West Africa, the Pacific islands and in some other parts of the humid tropics. *Xanthosoma* is an edible aroid and is sometimes confused with the polymorphic species *Colocasia esculenta*, which is also an edible aroid, some forms of which are called old cocoyams in West Africa. The name new cocoyam reflects its recent introduction into West Africa where *Colocasia* was previously established. It is an herbaceous plant that produces a main corm at the base with 10 or more lateral cormels up to 25 cm long (Kay 1987).

There was considerable variation in the composition of tannias and the starch content ranging from 17 to 34.5% has been reported (Kay 1987). Average approximate composition of the edible portion has been quoted by Kay (1987) as energy 556 kJ 100 g⁻¹, water 70–77%, carbohydrate 17–26%, protein 1.3–3.7%, fat 0.2–0.4%, fibre 0.6–1.9%, ash 0.6–1.3%, calcium 20 mg 100 g⁻¹, iron 1 mg 100 g⁻¹, thiamine 1.1 mg 100 g⁻¹, riboflavin 0.03 mg 100 g⁻¹, niacin 0.0005 mg 100 g⁻¹ and ascorbic acid 6–10 mg 100 g⁻¹. O'Hair and Asokan (1986) reported that the starch content varied considerably between the storage organs of different species of *Xanthosoma* (Table 129). In all cases cormels were higher in starch than corms. Also cormels had a higher mean dry matter at 38.8% compared to 29.2% for corms.

Harvesting

In Trinidad harvesting is usually some 9 months after planting when the leaves begin to turn yellow (Purse-glove 1972). Kay (1987) reported that a crop can

sometimes be harvested after 6 months. The onset of dormancy affects the storage life of corms and storage is no longer possible once sprouting occurs (O'Hair and Asokan 1986). Harvesting is carried out by carefully removing the soil from around the plant and harvesting the cormels while leaving the main corm in the ground to produce a further crop. Alternatively the whole plant may be dug up, the cormels removed and the main corm replanted (Campbell and Gooding 1962).

Curing

Wounds are made when the cormels are removed and also during trimming to remove the residual planting material from the base of the corms and the leaf bases. These regions have poor healing properties and require curing to prevent subsequent infection and spoilage. Traditionally curing is by placing corms in the sun or being placed in ventilated barns or other storage structures until the wounded surface dries out. It was recommended that brief exposure to tropical ambient conditions of 24 or 30 °C with 85% r.h. promoted curing of corms (Agbo-Egbe and Rickard 1991). Been *et al.* (1975) and Passam (1982) reported that curing corms at 35 °C and 95% r.h. for 5 days reduced their rate of sprouting and weight loss. Curing was less effective if damage on corms was extensive. The application of chemical to suppress sprouting has been suggested to have an inhibitory effect on wound healing and periderm formation (Passam 1982).

Storage

In common well-ventilated stores (an average of 26 °C and 76% r.h.) they had a weight loss of about 1% per week but sprouted after 6 weeks and were still considered edible after 9 weeks (Kay 1987). In Cameroon traditional storage in pits in a confined atmosphere has been found more satisfactory than storing on trays in well-ventilated huts (Praquin and Miche 1971). In Trinidad it was found that, when stored at ambient temperatures, there was a loss of eating quality after 8 weeks, but the quality was maintained for 18 weeks or more if the cormels were stored at 7 °C and 80% r.h. (Gooding and Campbell 1961). Traditional pit storage is generally more satisfactory than ventilated room or barn storage (Tindall

Table 129 Starch concentration (%) of *Xanthosoma* storage organs (source: adapted from O'Hair and Asokan 1986)

Species	Corm	Cormel
<i>X. atrovirens</i>	35.1	46.2
<i>X. caracu</i>	13.4	26.2
<i>X. violaceum</i>	10.6	22.9

1983). Recommendations for refrigerated storage include

- 7.2 °C and 80% r.h. for 18 weeks (Gooding and Campbell 1961);
- 7 °C and 80% r.h. for 120–130 days (Tindall 1983);
- 7–10 °C and 80% r.h. for 4–5 months (Snowdon 1991).

Transport

Export shipments at 13–14 °C from Puerto Rico to Chicago in the United States taking 9 days were generally in poor condition on arrival. In subsequent storage at 15 °C and 65% r.h. for 30 days 35% of the corms had decayed (Burton 1970).

Diseases

Diseases are similar to those given for *Colocasia esculenta* including *Fusarium* spp., *Rhizoctonia* spp., *Botryodiplodia theobromae*, *Ceratocystis* spp. and *Sclerotinia* spp. However, *Xanthosoma* spp. appear to be more resistant to postharvest diseases than *C. esculenta*. Waxing, fungicidal treatment and chlorine washes were all shown to reduce storage losses of the cormels (Burton 1970).

Taro

Araceae

Colocasia esculenta (L.) Schott. Other common names include dasheen, eddoe, cocoyam, malanga, old cocoyam, cocoyam, callaloo and coco. Some common names are used to refer to both *C. esculenta* and *Xanthosoma* spp. since both have similar uses. *C. esculenta* may be distinguished as taro, cocoyam or old cocoyam, while the term new *cocoyam* refers to species of *Xanthosoma*. The USDA database (2012f) gave the following species:

- *C. esculenta* (L.) Schott
- *C. esculenta* (L.) Schott var. *antiquorum* (Schott) Hubbard & Rehder
- *C. esculenta* (L.) Schott var. *aquatilis* Hassk.
- *C. esculenta* (L.) Schott var. *esculenta*
- *C. esculenta* (L.) Schott var. *nymphiifolia* (Vent.) A.F. Hill
- *C. indica* (Lour.) Kunth

- *C. antiquorum* Schott
- *Cladium colocasia* (L.) W. Wight. with a common name of malanga.

Kay (1987) stated that two types of *Colocasia esculenta* were frequently referred to as *separate species* in the literature, *C. antiquorum* and *C. esculenta*, but it is more generally accepted that it is one polymorphic species, *C. esculenta*. Under this classification the eddoe is *C. esculenta* var. *antiquorum* synonymous with *C. esculenta* var. *globulifera* which has a small corm surrounded by large cormels and the dasheen is *C. esculenta* var. *esculenta* which has a large central corm with a few small cormels.

Taro originated in India and is thought to have been cultivated for over 10,000 years. Ancient Roman and Greek historians mentioned it (Hedges and Lister 2006). Plucknett and White (1979) stated that Taro is believed to have originated in Southeast Asia including India and Malaysia. It spread to Myanmar, China, Formosa, Indonesia, Japan, Melanesia, Polynesia, the Solomon Islands and Hawai'i. In historical times it also spread to Egypt and the eastern Mediterranean, the Guinea coast of Africa and to the Caribbean with the African slaves (Kay 1987). It was the most important food throughout the Hawai'ian Islands.

The mature root is boiled as a starchy vegetable. It was the staple of the Hawai'ian diet where cultivars fall into two main groups. These are wetland Taro, the source of the Polynesian food 'poi', which is made from the main corm and upland Taro, which produce numerous eddoss that are used much like potatoes for cooking and in processing (Plucknett and White 1979). The leaves are high in minerals and vitamins A, B and C. These large leaves are cooked like mustard or turnip greens and the resulting product is called callaloo in the Caribbean. The young leaves are cooked and used for human consumption as a very nutritious vegetable and the corms are used as staple in place of rice or potato (Plucknett and White 1979). Taro is good for people allergic to milk or cereals and can be consumed by children who are sensitive to milk (Roth *et al.* 1967).

A herbaceous perennial grows up to 2 m high with an underground corm that produces a whorl of large leaves with long robust petioles at its apex (Figure 55). There are perhaps over a thousand recognized cultivars. Corm flesh colour can be various shades of white, yellow, red or purple.



Figure 55 Eddoes for sale in Huddersfield in the United Kingdom. See colour plate section.

Chemistry

Taro are a major source of starch, a good source of fibre and also contains potassium, small amounts of vitamin C, zinc, thiamine and folate but is low in protein and fat. However, they contain calcium oxalate in the form of needle-shaped crystals that can cause irritation when handled, eaten raw or undercooked and may lead to the formation of kidney stones. These crystals are broken down with long cooking. Generally Taro lacks antioxidant pigments, but the presence of anthocyanins has been found in coloured varieties (Hedges and Lister 2006). The composition of the edible portion of the corms has been given by Kay (1987) as energy 373–406 kJ 100 g⁻¹, water 73–78%, protein 1.4–3%, fat 0.1–1.5%, carbohydrate 19–21%, fibre 0.4–2.9%, ash 0.6–1.3%, calcium 32–40 mg 100 g⁻¹, iron 0.8–1.7 mg 100 g⁻¹, phosphorus 64–140 mg 100 g⁻¹, potassium 514–550 mg 100 g⁻¹, sodium 7–9 mg 100 g⁻¹, carotene trace to 67 IU 100 g⁻¹, thiamine 0.09–0.18 mg 100 g⁻¹, riboflavin 0.03–0.04 mg 100 g⁻¹, niacin 0.4–0.9 mg 100 g⁻¹ and ascorbic acid 0–10 mg 100 g⁻¹. The chemical content of corms was given by Coursey (1968) as starch 77.9%, pentosans 2.6%, dextrins 0.5%, reducing sugars 0.5%, sucrose 0.1%, amylose 17–28% and crude protein 1.4%. The starch grains are rich in mucilage, which on hydrolysis yielded eight sugars, the predominant ones were D-galactose and L-arabinose in the ratio 8:1. Both the leaves and petioles can be utilised as vegetables and are useful sources of vitamins A and C. Vitamin A in

Table 130 The composition of *Colocasia esculenta* for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Taro	Tahitian Taro
Water (g)	70.64	87.96
Energy (kcal)	112	44
Protein (g)	1.50	2.79
Total lipid (fat) (g)	0.20	0.97
Carbohydrate, by difference (g)	26.46	6.91
Total dietary fibre (g)	4.1	–
Sugars, total (g)	0.40	–
Calcium (mg)	43	129
Iron (mg)	0.55	1.30
Magnesium (mg)	33	47
Phosphorus (mg)	84	45
Potassium (mg)	591	606
Sodium (mg)	11	50
Zinc (mg)	0.23	0.09
Total ascorbic acid (mg)	4.5	96.0
Thiamine (mg)	0.095	0.062
Riboflavin (mg)	0.025	0.244
Niacin (mg)	0.600	0.995
Vitamin B-6 (mg)	0.283	0.116
Folate (µg_DFE)	22	9
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	4	102
Vitamin A (IU)	76	2045
Vitamin E (α-tocopherol) (mg)	2.38	–
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phyloquinone) (µg)	1.0	–
Fatty acids, total saturated (g)	0.041	0.197
Fatty acids, total monounsaturated (g)	0.016	0.078
Fatty acids, total polyunsaturated (g)	0.083	0.400

the leaves was 20,885 IU 100 g⁻¹ and in the petioles 335 IU 100 g⁻¹. Vitamin C in the leaves was 142 mg 100 g⁻¹ and in the petioles 8 mg 100 g⁻¹ (Kay 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 130.

Harvesting

Harvesting is usually some 9 months after planting when the leaves turn yellow and begins to die (Kay 1987). Other signs of maturity are when the main corms become clearly visible after pushing up to the soil surface. However, maturation varies between cultivars with most cultivars maturing between 6 and 12 months with a shorter time in drier areas and

the longer time in wetter areas. In Dominica the time to harvest is affected by different agro-ecological zones and in drier areas with an annual rainfall of less than 2500 mm they are ready for harvesting in 7 and 8 months and in the wetter areas with an annual rainfall between 3500 and 4500 mm it should be 9 and 10 months (Robin and Pilgrim 2004, Robin 2008). Corms harvested past the maturity stage can sometimes be unpalatable and when corms are harvested at the immature stage yields are reduced. Young taro leaves are also harvested, bunched and marketed as a leafy vegetable. Plucknett and White (1979) also found that harvesting of taro depended on the location of the crop and the variety planted. However, they found that most lowland plantings can be harvested in 12–15 months after planting if weeds are controlled. Taro growing on the warmer upland sites with good solar radiation will mature in about 12 months. Most of the taro grown in the lowlands or wetland areas are harvested by hand. The main corm and suckers are broken up and loosened from the soil and rotated in a circular fashion to cut and sever the roots. Corms can be harvested by placing a fork into the soil about 30 cm from the base of the plant and lifting gently and then placing the fork at the other side to prise the plant loose and gently pulled up by the leaf stalks (Robin and Pilgrim 2004).

Curing

Temperatures below 20 °C have been reported to cause very slow wound healing of dasheen cormels. It was recommended that brief storage of corms under tropical ambient conditions of 24–30 °C with about 85% r.h. promoted curing in taro corms (Agbo-Egbe and Rickard 1991). Under these conditions, wound healing occurred more readily at the top of corms than at the base and sometimes did not occur at the base. Snowdon (1991) reported that curing was most effective at 20–30 °C followed by cooling to control disease development.

Storage

This is a traditional staple crop in many countries and simple storage techniques have been developed over the centuries. As practised in some parts of the South Pacific, corms may be harvested with about 30 cm of

their basal petioles attached, tied into bundles and stored suspended in the shade. In pit storage, corms were placed inside pits and covered with leaves and soil. In parts of southern China, it is common practice to pile the corms in heaps and cover them with soil or seal them in leaf-lined pits in the ground. In parts of the Philippines, corms are stored on wooden platforms with the corms arranged in irregular rows and covered with dry grass and finally with soil (Plucknett and White 1979). Good ventilation is essential for storage. Storage losses can be reduced by minimizing the occurrence mechanical damage and leaving the corms untrimmed during storage (Cooke *et al.* 1988). It has been shown that they can be stored at tropical ambient conditions of 24–29 °C with 86–98% r.h. for at least 2 weeks (Agbo-Egbe and Rickard 1991). They found that there were no significant changes in crude protein and total amino acids but there was a significant reduction in starch and increase in total sugar content. During storage in well-ventilated stores at about 26 °C and 76% r.h., Tannia corms had 1% weight loss per week but sprouting occurred after 6 weeks. The corms were still edible after 9 weeks of storage (Thompson 1996). Other studies showed that Tannia corms may be stored in well-ventilated conditions for up to 6 months although loss of eating quality was observed after 8 weeks (Kay 1987). Ventilated storage of corms in the dark at 24 °C resulted in 30% decay after 1–3 weeks (Kay 1987). Factors such as corm maturity, environmental condition, agro-climatology, degree of physical damage and a host of pre-harvest factors contribute to the variability of results reported.

Anonymous (n.d. taro) stated 'The taro corm has limited – approximately 2 weeks – storage life post harvest'. In the Solomon Islands they were considered unfit for human consumption after only 1 or 2 weeks in ambient conditions mainly due to rotting caused by fungal infections (Gollifer and Booth 1973). However, corms can be stored in shaded pits where they may remain in good condition for up to 120 days (Tindall 1983) but in the Cameroons corms stored in trays for 6 months in ambient conditions had a loss of 95%. In parts of southern China, it is common practice to pile the corms in heaps and cover them with soil or seal them in leaf-lined pits in the ground (Plucknett and White 1979). At room temperature of 20 °C and 60% r.h. it was reported in

Mercantilia (1989) that they could be kept for 2–4 weeks. Recommendations for cold storage include

- 6.1–7.2 °C and 80% r.h. (Wardlaw 1937);
- 7–10 °C and 85–90% r.h. for 4–5 months (Lutz and Hardenburg 1968);
- 11.1–12.8 °C and 85–90% r.h. for 21 weeks (Pantastico 1975);
- 11–13 °C and 85–90% r.h. for 150 days for taro and cocoyam (Tindall 1983);
- 10 °C for up to 180 days (dasheen) (Tindall 1983);
- 10 °C for up to 6 months (Kay 1987);
- 4.4 °C for 3½ months (Kay 1987);
- 12 °C and 90% r.h. for 5 months (Mercantilia 1989);
- 7.2 °C and 85–90% r.h. for 120–150 days for taro root (SeaLand 1991);
- 13.3 °C and 85–90% r.h. for 42–140 days for dasheen or taro (SeaLand 1991);
- 7.2 °C and 70–80% r.h. for 90 days (Malanga) (SeaLand 1991);
- 11–13 °C and 85–90% r.h. for 5 months (Snowdon 1991);
- 7–10 °C with 80–95% r.h. for up to 18 weeks (Paull *et al.* 1999);
- 11–13 °C for up to 8 weeks (Paull *et al.* 1999);
- 20 °C for 2–4 weeks (Paull *et al.* 1999);
- 12–13 °C and 80–90% r.h. for 3–4 weeks for dasheen (Robin and Pilgrim 2004, Robin 2008);
- 7–14 °C and 85–90% r.h. (Hedges and Lister 2006).

Midmore *et al.* (2006) found that the quality of the corms remained acceptable after 8 weeks at either 7 °C or 20 °C, but storage at 20 °C, particularly with 90–95% r.h., resulted in excessive sprouting. Disease incidence increased between 4 and 8 weeks in storage at 7 °C to 5% of corms while at 20 °C it increased to 23%. They concluded that storage of corms was possible at 7–12 °C in a dark well-ventilated room for up to 8 weeks without compromising their quality.

Modified atmosphere packaging

Packing the corms in plastic bags reduced decay during 2 weeks of storage and was more effective when corms were pre-treated with benomyl (Quevedo *et al.* 1991). Benomyl use is not permitted in many countries. MA packaging in PE film bags of *Xanthosoma* and Taro at 27–32 °C reduced weight loss and

kept them in good condition (Passam 1982). Packing taro corms in plastic bags and closely tying the open end with rubber bands reduced the decay severity and percentage weight loss (Quevedo *et al.* 1991). For commercial handling purposes, packing in polyethylene bags often follows the selection of good quality corms, fungicide application and draining and air drying. It was reported that the storage life of corms in such bags was 26–40 days over those packed in cartons (Kay 1987). Modified atmosphere packaging in PE film bags has been shown to reduce postharvest losses. Both *Xanthosoma* and *Colocasia* stored in Trinidad ambient conditions of 27–32 °C showed reduced weight losses (Table 131), although the recommended optimum temperature for storage in non-controlled atmosphere storage or non-modified atmosphere packaging conditions varied from 7 to 13 °C. In comparison with traditional storage in trenches or pits, corms kept in PE bags survived well for up to 30 days without appreciable changes in taste and texture. Dipping corms in 1% common salt before storage in PE bags provided additional protection against fungal infection and the best storage results were obtained when the petioles and corm apex were left intact (Rickard 1983).

Other storage environments such as coir dust and hull ash have been reported to increase storage life and reduce the severity of decay of corms. In trials with Dasheen type, placing corms in a medium of rice hull ash extended its usual storage life of corms by 14 days and reduced the incidence of decay (Quevedo *et al.* 1991). Passam (1982) described a 6-week storage trial in which both *Colocasia* and *Xanthosoma* were put in boxes containing coir dust and stored in ambient conditions of 27–32 °C. Decay was about 50% in dry or wet coir for *Xanthosoma*, but it was 25% for *Colocasia* in dry coir and only 5% in moist coir. He concluded that for the best results, it was important to ensure that the moisture content of the coir was damp and not wet as the latter would facilitate the decay of corms.

Transport

Burton (1970) monitored export shipments from Puerto Rico to the United States. They were shipped at 13–14 °C and took an average of 9 days. Most corms were in poor condition on arrival and during subsequent storage at 15 °C and 65% r.h. for 30 days

35% of the cormels had decayed. This was reduced to 13% if the cormels were washed in 2500 µl L⁻¹ chlorine then waxed or 18% if they were dipped in 1000 µl L⁻¹ SOPP plus 900 µl L⁻¹ of Dichloran then waxed. Since that time there is more restriction on the use of postharvest chemicals.

Diseases and diseases

Postharvest losses are mainly due to poor harvesting techniques and inadequate postharvest handling practices, which cause corm damage thus facilitating fungal infection. The soil-borne fungi *Pithium splendens*, *Fusarium* spp., *Rhizoctonia* spp. and *Botryodiplodia theobromae* enter the corm through wounds and broken surfaces, causing tissue breakdown and flesh browning, which can on occasion extend deep into the corm. *Pythium* root rot can be a major problem in wetland taro. *Ceratocystis* spp. and *Sclerotinia* spp. have also been associated with corm rots and secondary infection soft rot caused by the bacteria *Erwinia chrysanthemi* also causes spoilage (Robin and Pilgrim 2004). After harvesting roots should be washed to remove soil and then any diseased tissue should be cut away and corms cured so that wound healing can occur (Snowdon 1991). Gollifer and Booth (1973) reported that a number of fungal organisms implicated in the storage rotting in the British Solomons Island Protectorate including *Aspergillus niger*, *Fusarium solani*, *B. theobromae*, *F. oxysporum*, *Corticium rolfsii*, *Geotrichum candida* and *Sclerotium rolfsii*. *Ceratocystis fimbriata* was found sporulating in grey to black discoloured areas on corms found in supermarkets and farmers' markets in the states of São Paulo, Rio de Janeiro, Bahia, Rondônia and the Distrito Federal in Brazil. The fungus is soil borne and it is believed that the corms became infected in the field and the rot progressed postharvest (Harrington *et al.*

2005). Fatima *et al.* (2009) found *Phytophthora capsici* infecting taro in on the market in Karachi, Pakistan, and its presence indicated preharvest infection when plants were over crowded or over fertilized with nitrogen.

Rotting of corms is a major factor in limiting their storage life. Quevedo *et al.* (1991) studied various ways of disease control. They found that field sanitation and the application of benomyl to the crop during the growing period consistently decreased the severity of decay of corms in storage. Combinations of pruning, mulching and fungicide application at 15 days prior to harvest delayed decay development. Dipping corms in hot water at 50 °C with 200 µl L⁻¹ benomyl suspension for 5 min was also effective, while immersion for longer periods damaged the corm tissue. Benomyl use is not permitted in many countries.

Striations (corky fibrous streaks) have been reported in the flesh of the white and common dasheen during the dry season. This has been attributed to physiological response of the corm to moisture stress (Robin 2008). Kay (1987) reported that corms are sometimes affected by the taro beetle (*Papuana* spp.). Taro had postharvest losses estimated at 30% in Côte d'Ivoire (Doumbia 1990).

Tomatoes

Solanaceae

Lycopersicon esculentum Miller, *L. lycopersicum* (L.) Karsten ex Farwell, *Solanum lycopersicum* L. Some authorities recognized the following: *L. esculentum* var. *cerasiforme* (Dun.) Alef. for cherry tomato (occurs wild in Ecuador and Peru), *L. esculentum* var. *pyriforme* Alef. for pear tomato, *L. esculentum* var. *grandifolium* Bailey for potato leaved tomato, *L. esculentum* var. *validum* Bailey for upright tomato and

Table 131 Effects of packaging on the percentage weight loss of stored *Colocasia* and *Xanthosoma* corms (source: adapted from Passam 1982)

Weeks in storage	<i>Colocasia</i>				<i>Xanthosoma</i>			
	Control	Dry coir	Moist coir	PE film	Control	Dry coir	Moist coir	PE film
2	11	7	0	1	8	7	0	1
4	27	21	3	5	15	19	4	3
6	35	30	7	9	28	28	21	6

L. esculentum var. *commune* Bailey for the common tomato (Purseglove 1972).

Tomatoes can also be divided into two types based on their growth patterns: determinate and indeterminate. Determinate plants are where the terminal bud can be a flower bud and side shoots continue growth. Indeterminate plants are where the flowers are produced on the stem with a strong side shoot in the leaf axil directly below. Indeterminate plants are usually grown as long stems and staked with the side shoots removed. Determinate plants are usually grown as bushes and also may be staked to protect the fruit from contact with the soil.

L. esculentum var. *cerasiforme* is reputed to have originated in the Ecuador and Peru areas and was first domesticated in Mexico. The Conquistadors introduced it into Europe after the conquest of Mexico in 1523 and it was described in Italy in 1544 and in England in 1597 where it was called the love apple (Purseglove 1972). The fruit is a berry and is usually red when ripe, but yellow cultivars and other shades are grown. Genetic engineering has produced fruit that do not soften normally. These can be harvested green and ripened in an atmosphere containing ethylene. One genetic engineered cultivar of tomato called Flavr Savr was marketed in the United States in 1993. It was also canned and marketed in the United Kingdom, but due to restrictions in marketing products of biotechnology in the European Union and other countries and consumer resistance, the market was restricted.

Chemical composition

More than 400 substances have been shown to contribute to the odour of tomatoes, but no single compound or simple combination of these compounds has the typical smell of ripe fruit (Hobson and Grierson 1993). In an extensive study of Californian processing tomatoes over 3 years Garcia and Barrett (2006) found that their range of lycopene content was 55–181 mg kg⁻¹ depending on year, cultivar and growing conditions. Temperatures greater than 32.2 °C during the growing season result in lower lycopene concentrations. The mean lycopene concentrations were 106 mg kg⁻¹ in 2000, 101 mg kg⁻¹ in 1999 and 88 mg kg⁻¹ in 2001 and lycopene concentration decreased during maturation on the plant. During maturation of red cultivars there was a 10 to

14-fold increase in the concentration of carotenoids, mainly lycopene (Fraser *et al.* 1994). In mature processing tomatoes, lycopene constitutes 80–90% of the total pigments present (Shi and Le Maguer 2000). Tomato breeders are developing high-pigment hybrid processing tomatoes that yield improved red colour for tomatoes and tomato products, as well as having larger concentrations of lycopene. Lycopene in fresh tomato fruits occurs essentially in the all-trans configuration. Shi and Le Maguer (2000) reported undesirable degradation of lycopene that not only affects the sensory quality of the final products but also their health benefits. The main causes of tomato lycopene degradation during processing are isomerization and oxidation. Isomerization converts all-trans isomers into cis-isomers due to additional energy input and results in an unstable, energy-rich station. In general, dehydrated and powdered tomatoes have poor lycopene stability unless carefully processed and promptly placed in a hermetically sealed and inert atmosphere for storage. Frozen foods and heat-sterilized foods exhibit excellent lycopene stability throughout their normal temperature storage shelf life. Farneti *et al.* (2012) reported a survey among consumers that indicated that tomatoes were most often stored in refrigerators at well below 10 °C. They tested two cultivars (cocktail and round type) at the red ripe stage during 20 days of storage at 4, 8, 12 and 16 °C and found that temperatures below 12 °C caused discolouration and reduced their lycopene contents. The chemical content was given by USDA Nutrient Database (2012a) in Table 132.

Harvesting

Harvest maturity is determined by skin colour and the OECD has produced a colour chart that shows photographs of 12 fruits ranging in colour from green to red (Figure 56). Tomatoes that are fully red at harvest may be soft and susceptible to handling damage or become over ripe and unacceptable in the marketing chain. In practice fruit are normally harvested at the stage when they just turning from green to red. At this stage they are still firm and bruise less during handling, grading and packing. TA was lower in fruits harvested at the firm red stage and decreased during storage (Chiesa *et al.* 1998) and the best flavoured fruit were those that ripened fully on the plant. Zhang and McCarthy (2012) reported

Table 132 The composition of tomato fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Green	Ripe (year round average)
Water (g)	93.00	94.52
Energy (kcal)	23	18
Protein (g)	1.20	0.88
Total lipid (fat) (g)	0.20	0.20
Carbohydrate, by difference (g)	5.10	3.89
Total dietary fibre (g)	1.1	1.2
Sugars, total (g)	4.00	2.63
Calcium (mg)	13	10
Iron (mg)	0.51	0.27
Magnesium (mg)	10	11
Phosphorus (mg)	28	24
Potassium (mg)	204	237
Sodium (mg)	13	5
Zinc (mg)	0.07	0.17
Total ascorbic acid (mg)	23.4	13.7
Thiamine (mg)	0.060	0.037
Riboflavin (mg)	0.040	0.019
Niacin (mg)	0.500	0.594
Vitamin B-6 (mg)	0.081	0.080
Folate (µg_DFE)	9	15
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	32	42
Vitamin A (IU)	642	833
Vitamin E (α-tocopherol) (mg)	0.38	0.54
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Vitamin K (phylloquinone) (µg)	10.1	7.9
Fatty acids, total saturated (g)	0.028	0.028
Fatty acids, total monounsaturated (g)	0.030	0.031
Fatty acids, total polyunsaturated (g)	0.081	0.083

some success in using magnetic resonance imaging for tomato maturity classification on the basis of skin colour. Van de Poel *et al.* (2012) tested a model using only fruit colour (expressed as hue) and mass. They calibrated it against a dataset from the cultivar Bonaparte during development and ripening. They then successfully used this model-based classification to classify individually harvested fruit at different stages of development and successfully used it on the cultivar Plaisance.

Harvesting is by hand when each individual fruit reaches the acceptable colour. They are twisted so that the pedicel breaks at the abscission point so that they are harvested with the calyx still attached. The stem scar is the major pathway for internal and external gas

**Figure 56** Colour chart to facilitate colour grading of tomatoes. (Source: OECD 2003. Reproduced with permission.)

exchange (Yang *et al.* 1999) and leaving the pedicel attached may allow for internal depletion of O₂ and increase in CO₂ this slowing the rate of ripening. Some cultivars are available where all the fruit in a truss ripen at the same time and the whole truss can be harvested by clipping it from the plant. In some cases they are harvested fully ripe and packed and marketed on the truss at a premium price.

Quality

The OECD published a brochure of standards for tomatoes in 1988 which also included a colour chart to facilitate harvest and grading standards. Much research work has been done on objective methods of measuring the maturity or ripeness of tomatoes. Much of this work is really for quality grading since it must be done postharvest. Delayed luminescence can be used as a non-destructive indicator of soluble solids and dry matter of cherry tomato fruit (Triglia *et al.* 1998). Acoustic and vibration tests equipment puts energy into a fruit and measures its response to this input. Good correlations have been found using the second resonant frequency to determine tomato maturity (Darko 1984, Punchoo 1988). Delayed light emission has also been used on tomatoes (Forbus *et al.* 1985) objectively to grade fruit into different maturity groups postharvest. This is based on the chlorophyll content of the fruit, which reduces during maturation. The fruit is exposed to a bright light and then switched off so the fruit is in the dark. A sensor measures the amount of light emitted from

the fruit, which is proportional to its chlorophyll content and thus its maturity. The wavelength of peak transmittance of light through fruits was shown to have good correlation with their maturity (Birth and Norris 1958). This was tested on tomatoes and a portable easy to use instrument was developed which was non-destructive. Mechanical resonance techniques have been applied to tomatoes (de Baerdemaeker 1989). The stiffness factor in tomatoes was shown to decrease during storage and was used to develop a small device to objectively measure fruit maturity.

Prestorage treatments

Postharvest application of calcium has also been shown to inhibit ripening of tomatoes (Wills and Tirmazi 1979). Treatment of fruits prior to storage in atmospheres of total nitrogen was also shown to retard subsequent ripening of tomatoes (Kelly and Saltveit 1988). Yang *et al.* (1999) found that sealing of the stem scar of the cultivar Floradade greatly reduced the ripening rate and extended the storage life. After 70 days at room temperature, the sealed fruits were still in good condition with some uneven red colour on the shoulder, while the unsealed fruits were fully ripe within 20 days. After sealing the stem scar, the O₂ level in sealed fruits decreased rapidly and dropped below 3% within 2 days, while the internal CO₂ level increased to about 6% in the following few days.

1-MCP was applied for 12 h at $22 \pm 1^\circ\text{C}$ and 80–85% r.h. During subsequent storage at $20 \pm 1^\circ\text{C}$ and 85–95% r.h. 1-MCP delayed ripening by 8–11 days for 250 ml L⁻¹, 11–13 days for 500 ml L⁻¹ and 15–17 days for 1000 ml L⁻¹ compared to non-treated. After 17 days fruit treated with 1000 ml L⁻¹ were firmer and greener, but total carotenoids were lower than in non-treated fruit (Moretti *et al.* n.d.). Both 1 µl L⁻¹ 1-MCP for 24 h and controlled atmosphere storage in 2% O₂ + 3% CO₂ significantly delayed colour development and softening. The effect at 1 µl L⁻¹ was greater than the effect of controlled atmosphere storage but 1-MCP at 0.5 µl L⁻¹ had no effect (Amodio *et al.* 2005). Baldwin *et al.* (2007) harvested the cultivar Florida 47 at immature green, green, breaker, turning and pink stages and treated half of them with 1-MCP and stored them all at 18 °C. Fruits treated with 1-MCP had slightly lower

levels of most aroma volatiles but ripened slower by 3–4 days compared to non-treated fruit, but at 13 °C the delay in ripening of 1-MCP-treated fruit was only 2–3 days. They reported that 1-MCP seemed to synchronize ripening of pink stage tomatoes. Hai and Gubler (2012) found that after natural or artificial infection with *Alternaria alternata*, *Botrytis cinerea* and *Fusarium* spp. disease incidence and severity after 31–42 days of storage of the cultivars Quality 23 and Seminis 35 harvested at the green or pink stages was significantly reduced in 1-MCP-treated fruit compared with those that had not been treated. There was one exception in the inoculated test of Quality 23 where severity of *Alternaria* rot in 1.0 µl L⁻¹ treated fruit were significantly higher than that of the untreated control. The 1-MCP treatments they used were zero and 0.6 µl L⁻¹ for 12 h and 1.0 µl L⁻¹ for 6 h. Ali *et al.* (2010) found that tomatoes harvested at the green-mature and breaker stages and coated with a 10% aqueous solution of gum arabic had delayed ripening. They found that this treatment extended their storage life at 20 °C and 80–90% r.h. by up to 20 days without any spoilage and off-flavour. Sensory evaluation proved the efficacy of 10% gum arabic coating by maintaining the overall quality of tomato fruit during the storage period.

Pre-cooling

Crops such as tomatoes, which have a relatively thick wax cuticle, are not suitable for vacuum cooling, but they can be successfully hydrocooled or cooled in a forced air pre-cooler.

Respiration rate

In mature green and pink fruits respiration rates and ethylene production were lower in CA than in air (Loughheed and Lee 1989). Low O₂ in the store atmosphere was shown to reduce their respiration rate with the effect being greater at the higher temperatures (Table 133). At colour stage 1 there was no lycopene present. At colour stage 2 the level of lycopene was still very low but increased rapidly as they turned from pink to light red at colour stage 4 to stage 5 but lycopene concentration did not increase from stage 5 to stage 6 (Schauwers *et al.* 2006). At colour stages 5 and 6 the TSS was about 40 mg 100 g⁻¹.

Table 133 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of Eurocross BB tomatoes (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	6	9	15	23	30
In 3% O ₂	4	–	6	–	12

Storage

Mature green fruits will freeze at about -1.0 to -0.8 and ripe fruits at -1.0 to -0.7 °C (Wright 1942) or -1.28 to -0.50 °C (Weichmann 1987). Chilling injury in storage is related to the stage of ripeness of fruits. Thompson (1972b) showed that tomatoes at the green and turning stages suffered from chilling injury below 13 °C, but fully ripe fruits could be stored at 0 °C. The presence of ethylene in the storage atmosphere had no effect on chilling sensitivity. This was shown for green tomatoes where storage at 5 °C with or without 50 µl L⁻¹ ethylene had the same chilling injury effects (Manzano-Mendez *et al.* 1984). Low-temperature storage can inhibit the decline in acids during ripening and thus affect their flavour (Hulme 1971). Refrigerated storage recommendations were as follows:

Mature green fruits

- 1.5–3 °C and 85–90% r.h. for 6 weeks (Anonymous 1967);
- 12.8–15.6 °C and 85–90% r.h. for 2–6 weeks (Phillips and Armstrong 1967);
- 12.8–21.1 °C and 85–90% r.h. for up to 2 weeks (Anonymous 1968, Lutz and Hardenburg 1968);
- 8.9–10 °C and 85–90% r.h. for 4–5 weeks with 5.2% loss (VC lines) (Pantastico 1975);
- 1.7–3.3 °C and 85–90% r.h. for 6 weeks with 4.8% loss (Oxheart, Hybrid 6, Marathi) (Shipway 1968);
- 7.5–8 °C and 85% r.h. for 10 days (Moneymaker which are a quarter ripe) (Shipway 1968);
- 13.3 °C and 90–95% r.h. (SeaLand 1991);
- 12–15 °C and 90% r.h. for 1–2 weeks for mature green (Snowdon 1991);
- 10–12 °C and 90% r.h. for 1–2 weeks for turning (Snowdon 1991).

Red fruits

- 0 °C and 85–90% r.h. for 1–3 weeks (Anonymous 1967);

- 10 °C and 85–90% r.h. (Phillips and Armstrong 1967);
- 0–3.3 °C (Phillips and Armstrong 1967);
- 2–4 °C and 85–90% r.h. for 2–4 weeks (Anonymous 1967);
- 7.2–10 °C and 85–90% r.h. for several days (Lutz and Hardenburg 1968);
- 2–4 °C (Shipway 1968);
- 1–4 °C and 90% r.h. for 19 days (Manalucie) if marketed quickly after removal from storage (Thompson 1972b);
- 7.2 °C and 90% r.h. for 1 week (VC lines) (Pantastico 1975);
- 0–1.7 °C and 85–90% r.h. for 2 weeks (Sioux) (Pantastico 1975);
- 2 °C and 85–90% r.h. for 40 days (Tindall 1983);
- 10 °C and 85–90% r.h. for 35 days (Tindall 1983);
- 21 °C and 85–90% r.h. for 21 days (Tindall 1983);
- 11–14 °C and 80–85% r.h. for firm ripe for 2 weeks (Mercantilia 1989);
- 8–10 °C and 80–85% r.h. (Mercantilia 1989);
- 8–10 °C and 90% r.h. for 1 week (Snowdon 1991);
- 7–14 °C and 90–95% r.h. for breaker to light pink stage (SeaLand 1991).

Intermittent warming

In an experiment the cultivar Daniela F₁ at the breaker stage were treated with iprodione (1 g L⁻¹) and stored for 14 or 21 days at 6, 9 or 12 °C with 90–95% r.h. Some fruits stored at 6 and 9 °C were exposed to intermittent warming (20 °C for 1 day) at 7 day intervals. After storage, fruits were ripened at 20 °C and 75–80% r.h. for 3 days. Compared with cold storage, intermittent warming enhanced colour and promoted ripening. After ripening, no significant differences were observed in soluble solids content, but intermittent warming did reduce their TA (Artes *et al.* 1998). In experiments by Biswas *et al.* (2012) intermittent warming to 20 °C for 24 h every 7 days during storage at 2.5 or 6 °C reduced decay incidence in tomatoes grown in both New Zealand and Florida. However, chilling injury symptoms and intermittent warming efficacy were highly dependent on cultivar and/or production conditions. Intermittent warming enhanced red colour development in storage at 6 °C for the cultivar Cedrico grown in a greenhouse in New Zealand but did not improve it in the cultivar Soraya grown in the field in Florida.

Intermittent light

Aborisode and Ayibiowu (2010) studied the effects of postharvest day length on ripened the tomato cultivars Roma and Beske. They were harvested at the mature green, breaker, turning or pink stages and then stored at 28 °C either in 12 h alternating light and dark or in complete darkness. Ripening progressed in complete darkness more quickly than in alternating light and dark in breaker fruit. However, the difference was more pronounced in Roma than in Beske. Fruit initially at the turning stage did not show any significant effect of photoperiod in Roma but did by day 6 in Beske. Generally photoperiod had more significant effect at the mature green and breaker stages than at the turning and pink stages of ripening.

Controlled atmosphere storage

Storage in low concentrations of O₂ had less effect on tomatoes that were subsequently ripened than the stage of maturity at harvest (Kader *et al.* 1978). Increases in ethylene evolution and respiration, red colour development and loss in fruit firmness were delayed in mature green tomato fruits held in 3% O₂ compared with control fruits held in air which showed normal ripening-related changes at 20 °C (Kim *et al.* 1999). High CO₂ can result in uneven ripening (Morris and Kader 1977) and surface blemishes (Tomkins 1965). Pantastico (1975) also found that storage in atmospheres containing over 4% CO₂ or less than 4% O₂ gave uneven ripening. Batu (1995) stored the cultivar Criterium in controlled atmosphere conditions for 60 or 70 days at 15 °C followed by air for another 10 days at 20 °C for ripening. All tomatoes stored in either 1–3% O₂ or 3–9% CO₂ kept their green colour for 40–50 days. Acidity levels were similar in all treatments except the fruits stored in 1% O₂ or 9% CO₂ were significantly lower. Soluble solids of fruit stored in air or in 1% O₂, particularly after 40 days of storage, were significantly lower than in other treatments. While the greatest deterioration occurred in fruits stored in air or in 1% O₂ with 5% CO₂, the least occurred in 3% CO₂ with 5.5% O₂. Storage recommendations were as follows:

- 12 °C in 5% CO₂ + 5% O₂ for fruits harvested at the yellow or 'tinted stage' (Wardlaw 1937);
- 12.8 °C in 3% O₂ + 5% CO₂ (Parsons and Spalding 1972);

- 12 °C in 2.5–5% CO₂ + 2.5% O₂ for 3 months (Monzini and Gorini 1974);
- 12.8 °C and 0% CO₂ with 3% O₂ for 6 weeks (Pantastico 1975);
- 12.8 °C and 1–2% CO₂ with 4–8% O₂ for breaker or pink fruit (Pantastico 1975);
- 12–20 °C with 0% CO₂ and 3–5% O₂ for mature green fruits, which had a good effect but was of limited commercial use (Kader 1985);
- 10 °C with 90% r.h. in 8% CO₂ + 5% O₂ for up to 36 days for the cultivars Angela and Kada harvested at the mature green stage (Vidigal *et al.* 1979);
- 8–12 °C with 0% CO₂ and 3–5% O₂ for partially ripe fruit which had a good effect but was of limited commercial use (Kader 1985);
- a maximum of 2% CO₂ and a minimum of 3% O₂ (Fellows 1988);
- 12–20 °C with 2–3% CO₂ and 3–5% O₂, which had only a slight effect (Saltveit 1989);
- 12–13 °C with 0% CO₂ and 2% O₂, 5% CO₂ and 3% O₂ or 5% CO₂ and 5% O₂ for 6–10 weeks for mature green tomatoes (Adamicki 1989);
- 0% CO₂ with 3–5% O₂ or for breaker to light pink 0–3% CO₂ with 3–5% O₂ for mature green (SeaLand 1991);
- 13 °C in 9.1% CO₂ + 5.5% O₂ for 60 days for the cultivar Criterium harvested at the pink stage of maturity (Batu and Thompson 1995);
- 10–15 °C in 3–5% CO₂ + 3–5% O₂ (Bishop 1996).

At 12.8 °C fruit colour and flavour were maintained in an acceptable condition for 6 weeks in 0% CO₂ + 3% O₂, while in other work 1–2% CO₂ + 4–8% O₂ at 12.8 °C for breaker or pink fruit was recommended (Pantastico 1975). Adamicki (1989) described successful storage of mature green tomatoes at 12–13 °C in 0% CO₂ + 2% O₂, 5% CO₂ + 3% O₂ or 5% CO₂ + 5% O₂ for 6–10 weeks. Parsons *et al.* (1974) harvested tomatoes at the mature green stage and stored them at 12.8 °C for 6 weeks and found that 0% CO₂ + 3% O₂ was better than those stored in air. Fruits in air were fully red in 6 weeks, those in 0% CO₂ + 3% O₂ or those in 5% CO₂ + 3% O₂ fruits were still pink with the latter combination having an additional delaying effect on ripening. Dennis *et al.* (1979) stored fruits harvested at the mature green stage at 13 °C and 93–95% r.h. in air and 5% CO₂ + 3% O₂ or

5% CO₂ + 5% O₂ for 6–10 weeks. Two greenhouse grown cultivars (Sonato and Sonatine) and three field grown (Fortuna, Hundrefold and Vico) were used. Controlled atmosphere stored fruit were found to ripen more evenly and to a better flavour when removed from storage than air stored fruit, with the 5% CO₂ + 3% O₂ treatment giving the best quality fruit. Mature green fruits of the cultivars Saba and Saul were stored by Anelli *et al.* (1989) for 14 days at 12 °C in a room equipped with an ethylene scrubber or 40 days at 12 °C in 3% O₂ and 3% CO₂. At the end of storage the fruits had a marketable percentage of 90 and 85% for ethylene scrubber and CA storage, respectively. *Phytophthora* decay appeared on some fruits by the end of CA storage. Tataru and Dobresanu (1978) showed that tomatoes kept best in 3% CO₂ + 3% O₂. Greenhouse grown mature green and pink tomatoes of the cultivar Veegan were stored in air or in 0.5, 3.0 or 5.0% O₂ in N₂ or argon. Colour development was not affected by the background gases N₂ or argon except at 3% O₂ where ripening was delayed by the argon mixture. All the levels of O₂ suppressed colour development in mature green fruits compared with those stored in air, with maximum suppression in 0.5% O₂. Most fruits held in 0.5% O₂ rotted after removal to air before colour development was complete.

Green mature tomatoes of the cultivar Ramy were stored for 20 days at 4 or 8 °C in 3% O₂ + 0% CO₂ with or without ethylene removal or in 1.5% O₂ + 0% CO₂ with ethylene removal using potassium permanganate. Fruit ripening was delayed in most in fruits stored in 1.5% O₂ + 0% CO₂ with ethylene removal (Francile 1992). The colour of fruit harvested at the pink stage did not change when they were stored in 6.4% CO₂ + 5.5% O₂ and 9.1% CO₂ + 5.5% O₂ even after 50 days and in some cases after 70 days of storage. The red colour development of the tomatoes exposed to less than 6.4% CO₂ increased, whereas red colour decreased with CO₂ levels above 9.1% during storage (Batu 1995). Storage in atmospheres containing greater than 4% CO₂ or less than 4% O₂ gave uneven ripening (Pantastico 1975). Li *et al.* (1973) showed that O₂ levels below 1% caused physiological injury during storage, owing presumably to fermentation. The minimum O₂ level for prolonged storage at 12–13 °C was about 2–4% O₂, which delayed the climacteric peak. Salunkhe and Wu (1973) showed that exposing 'green-wrap' fruits of the cultivar DX-54

to low O₂ atmospheres at 12.8 °C inhibited ripening and increased storage life. Storage at 10% O₂ + 90% N₂ resulted in a storage life of 62 days and in 3% O₂ + 97% N₂ it was 76 days. The maximum storage life was 87 days at 1% O₂ and 99% N₂. Low O₂ atmospheres inhibited fruit chlorophyll and starch degradation and also lycopene, β -carotene and sugar synthesis. Parsons and Spalding (1972) inoculated fruit with soft rot bacteria and held them for 6 days at 12.8 °C. Decay lesions were smaller on fruits stored in 3% O₂ + 5% CO₂ than on those stored in air, but CA storage did not control decay. However, although at 12.8 °C inoculated tomatoes kept better in CA storage than in air, at 7.2 or 18.3 °C they kept equally well in controlled atmosphere storage and air.

Moura and Finger (2003) harvested Agriset at breaker maturity (less than 10% red colour) and stored them in 2, 3, or 4% O₂ or air 14 days at 12 °C then ripening in air at 20 °C. They found that there were no difference in volatile content of the fruit except for cis-3-hexenal and 2 + 3-methylbutanol. The other volatiles they measured were acetone, methanol, ethanol, 1-penten-3-one, hexanal, trans-2-hexenal, trans-2-heptenal, 6-methyl-5-hepten-2-one, cis-3-hexenol, 2-isobutylthiazole, 1-nitro-2-phenylethane, geranylacetone and β -ionone levels among the treatments. Tomatoes were harvested at the mature green and pink stages of maturity and then stored for 60 days in air or 3.2% CO₂ + 5.5% O₂ or 6.4% CO₂ + 5.5% O₂ or 9.1% CO₂ + 5.5% O₂ at 15 °C for mature green and 13 °C for pink. Fruits stored in air at 15 °C had significantly better flavour and were sweeter and more acceptable than those in any of the CA conditions (Batu 2003).

Carbon monoxide

The addition of carbon monoxide to the storage atmosphere can have beneficial effects on tomatoes. A combination of 4% O₂, 2% CO₂ and 5% carbon monoxide was shown to be optimum in delaying ripening and maintaining good quality of mature green tomatoes stored at 12.8 °C after being subsequently ripened at 20 °C (Morris *et al.* 1981). The level of chilling injury symptoms was reduced, but not eliminated when carbon monoxide was added to the store. Carbon monoxide was also found to stimulate respiration rate, but this effect could be minimized by reducing the level of O₂ in the store to

below 5% (Kader 1987). Decay in stored mature green tomatoes stored at 12.8 °C was reduced when 5% CO₂ was included in the storage atmosphere (Morris *et al.* 1981).

Modified atmosphere packaging

At United Kingdom ambient temperature with about 90% r.h. partially ripe tomatoes, packed in suitably permeable plastic film giving 4–6% CO₂ + 4–6% O₂ can be expected to have 7 days longer shelf life than those stored without wrapping (Geeson 1989). Under these conditions the eating quality was reduced but film packaging that results in higher CO₂ and lower O₂ levels may not only prevent ripening but result in tainted fruit when they were ripened after removal from the packs. He also showed that film packages with lower water vapour transmission properties can encourage rotting. Batu (1995) showed that there were interactions between modified atmosphere packaging and temperature in that modified atmosphere packaging was more effective in delaying ripening at 13 °C than at 20 °C. Modified atmosphere packaging interacted also with harvest maturity where it was more effective in delaying ripening of fruit harvested at the mature green stage than for those harvested at a more advanced stage of maturity. Batu and Thompson (1994) stored tomatoes at both the mature green and the pink stage of maturity either non-wrapped or sealed in PE films of 20, 30 or 50 µm thickness at either 13 or 20 °C for 60 days. All non-wrapped pink tomatoes were over-ripe and soft after 30 days at 13 °C and after 10–13 days at 20 °C. Green tomatoes sealed in 20 and 30 µm film reached their reddest colour after 40 days at 20 °C and 30 days at 13 °C. Fruit in 50 µm film still had not reached their maximum red colour even after 60 days at both 13 and 20 °C. All green tomatoes sealed in PE film were very firm even after 60 days of storage at 13 and 20 °C. Non-wrapped tomatoes remained acceptably firm for about 50 days at 13 °C and 20 days at 20 °C. Tano *et al.* (2007) stored mature green tomatoes at 13 °C in containers where some 5% O₂ + 5% CO₂ was maintained and subjected to a sequence of temperature fluctuations of 10 °C for 35 days. Temperature fluctuations had a major impact on the composition of the package atmospheres and on product quality. CO₂ concentrations increased rapidly, reaching a maximum of 11% while O₂ concentrations decreased

to less than 1.5%. The temperature fluctuating regime resulted in extensive browning, softening, weight loss increase, ethanol increase and infection due to physiological damage and excessive condensation, compared to those stored at constant temperature.

Ripening

At the green stage of maturity tomatoes contain a toxic alkaloid called solanine, which decreases during ripening and chlorophyll levels are progressively broken down into phytol. It was observed that in cherry tomatoes the total chlorophyll level was reduced from 5490 µg 100 g⁻¹ f.w. in green fruit to 119 µg 100 g⁻¹ f.w. in dark red fruit (Laval Martin *et al.* 1975). Concurrent with this degradation process lycopene, carotenes and xanthophylls were synthesized giving the fruit its characteristic colour, usually red (Grierson and Kader 1986). Total carotenoids in cherry tomatoes increased from 3297 µg 100 g⁻¹ f.w. in green fruit to 11,694 µg 100 g⁻¹ f.w. in dark red fruit. This colour development occurred in both the pulp and the flesh. The optimum temperature for colour development was 24 °C while at 30 °C and above lycopene was not formed (Laval Martin *et al.* 1975).

Exposing tomatoes to ethylene can result in the rapid breakdown of chlorophyll (Lougheed and Franklin 1970). Application of ethylene to stored tomatoes was shown to increase their carotenoid and lycopene content (Haard and Salunkhe 1975). This appears to be additional to the increase that is normally associated with ripening. Green tomatoes exposed to high levels of ethylene (8000 µl L⁻¹) for a day and then ripened had 16% more ascorbic acid when ripe than untreated fruit (Watada *et al.* 1976). It has been shown that ethylene can reduce the growth of *Fusarium oxysporum* and rotting in tomatoes infected with the fungus (Lockhart *et al.* 1969).

Non-ripening genetically modified cultivars have been produced. Crosses between these and wild types produced F₁ hybrids that will over-ripen very slowly. Evenness of ripening, greater depth of colour and some disease resistance have also been introduced into these transgenic tomatoes (Hobson 1989, Hobson and Grierson 1993).

The best quality in terms of colour and flavour is achieved by allowing the fruit to ripen fully before harvest (Hobson 1989). Harvesting fruit before they have fully ripened and then ripening them under

controlled conditions resulted in fruit of inferior flavour and aroma than those allowed to ripen fully on the plant (Hayase *et al.* 1984). Under-ripe fruit that were stored under refrigeration and not allowed to recover before consumption had poor flavour (Hobson and Grierson 1993). In spite of this storage of mature green fruit at 10 °C for 10 days then ripening at 21 °C for 2–6 days followed by storage at 10 °C for a further 8–10 days was recommended for the production of high quality fruit (Hulme 1971). Storage at 30 °C inhibited fruit ripening in that they became orange or yellow rather than red, but coloration may be improved by reducing the temperature to 18–24 °C (Tindall 1983). At 13–18 °C and 85–90% r.h. fruits were likely to ripen in 14–16 days (Tindall 1983).

Ripening at 18.3–20 °C could be shortened by 2 days in the atmosphere was enriched with 200 µl L⁻¹ ethylene (Lutz and Hardenburg 1968). Ripening at 13–22 °C with 10 µl L⁻¹ of ethylene continuously was recommended by Wills *et al.* (1989). Fruit exposed to 100 µl L⁻¹ ethylene for 48 h had a higher rate of ripening at 20 °C, but this resulted in a higher reduction in ascorbic acid content when fruits were ripe than when fruits were ripened without exogenous ethylene (Kader *et al.* 1978). However there was no significant difference in flavour between tomatoes ripened with or without ethylene. At 20 °C Wills *et al.* (2001) found that the time to ripen increased linearly with logarithmic decrease in ethylene concentration over the range of less than 0.005, up to 10 µl L⁻¹.

Diseases

During production fruit are subject to many fungal diseases, which may be carried through and develop postharvest. These preharvest infections may be exacerbated when tomatoes are grown in greenhouses because the high humidity may result in condensation on the fruit that may provide a suitable environment for fungi to grow and develop. Wei (1995) studied this factor and showed that appropriate ventilation of the greenhouses could be a major factor in controlling fruit infections. Fungal diseases of fruit include alternaria rot or black rot (*Alternaria alternata*), fusarium rot (*Fusarium* spp.), grey mould (*Botrytis cinerea*), mucor rot (*Mucor mucedo*), phoma rot (*Phoma* spp.), phomopsis rot (*Diaporthe* spp.), phytophthora or buckeye rot (*Phytophthora* spp.),

pleospora rot (*Pleospora herbarum*, *Stemphylium botryosum*), rhizopus rot (*Rhizopus stolonifer*, *R. oryzae*), ring rot (*Myrothecium roridum*), sclerotium rot (*Sclerotium rolfsii*), sour rot (*Geotrichum candidum*); target spot (*Corynespora cassiicola*) and watery soft rot (*Sclerotinia minor*, *S. sclerotiorum*). Bacterial decays include soft rots (*Bacillus* spp., *Erwinia carotovora* ssp., *Pseudomonas* spp. and *Xanthomonas campestris*); lactic acid decay (bacterial sour rot) (*Lactobacillus* spp. and *Leuconostoc mesenteroides*). Control is mainly through careful handling during harvesting and transport and good sanitation (Jones *et al.* 1991, Snowdon 1992, Bartz *et al.* 1995).

Physiological disorders

Snowdon (1992) reviewed the many physiological disorders of tomato fruit. Blotchy ripening is characterized by the development of green or green-yellowish areas on the surface of red tomato fruit. Moretti *et al.* (2000) reported that it was associated with nutrient deficiency particularly potassium and nitrogen. Sunburn is associated with high temperature during fruit development that may disrupt lycopene synthesis resulting in the appearance of yellow areas in the affected tissues that remain during the ripening process. Blossom-end rot begins in the green fruit as a small discolouration at the blossom end that increases in size and becomes dry and dark-brown. It is related calcium deficiency and fungal infection can occur in weakened tissues. Internal bruising can cause yellow to green locular gel in ripe tomatoes. Breaker-stage fruit are more sensitive to internal bruising than those handled at the green stage (Sargent *et al.* 1992).

Tomatillo

Solanaceae

Physalis philadelphica Lam., *P. ixocarpa* Brot. Ex Hornem, *P. aequata* Jacq., also called Mexican husk tomato, *Mayan husk tomato*, *tomate de cáscara*, *tomate verde*, *tomate Mexicano*, *tomate de fresadilla*, *tomate de culebra*, *tomatillo*, *miltomate* and *farolito*. In contrast with goldenberry (*P. peruviana*). It is used mainly as a vegetable and in Mexico it is generally made into a sauce for meat (salsa verde) alone or together with green chilli peppers. When ripe it is

Table 134 The composition of the edible portion of tomatillo fruits 100 g^{-1} from analyses of the husked fruit made in Guatemala and India (source: Morton 1987)

Moisture	90.4–91.7 g	Ionizable iron	1.0 mg
Protein	0.171–0.7 g	Sodium	0.4 mg
Fat	0.6 g	Potassium	243 mg
Carbohydrates	5.8 g	Copper	0.09 mg
Fibre	0.6–1.7 g	Sulphur	27 mg
Ash	0.6–0.69 g	Chloride	14 mg
Calcium	6.3–10.9 mg	Carotene	0.061–0.074 mg
Magnesium	23 mg	Thiamine	0.054–0.106 mg
Phosphorus	21.9–40 mg	Riboflavin	0.023–0.057 mg
Phytin	7 mg	Niacin	2.1–2.7 mg
phosphorus			
Iron	0.57–1.4 mg	Ascorbic acid	2–4.8 mg

often consumed as a fresh fruit. It is native to the highlands of Guatemala and Mexican and was a staple for the Aztecs and Mayans. It was introduced into India in the 1950s and it has been cultivated in Australia and in South Africa. In 1967 it was reported to be an important agricultural weed in the highlands of Kenya (Morton 1987).

The plant, which is a semi-woody annual, may attain a height of 1.2–1.5 m but is often prostrate and spreading. Flowers are yellow and borne singly in the leaf axils. The fruit are berries that are spherical or slightly oblate, 2–6 cm wide and green or green-purple. As the fruit develops, the calyx enlarges to more or less enclose it and finally becomes straw-coloured and papery. It is so tight-fitting that it often bursts. When ripe, its thin skin may be yellow, purple or more rarely reddish or it remains green. The flesh is pale-yellow, crisp or soft and acid, subacid, sweet or insipid and contains many tiny seeds (Morton 1987). The composition of fruit is given in Table 134.

Harvesting

Tomatillos can be harvested at various stages of development, but for use in sauces, they should be harvested when they are still bright-green. Over-mature fruit that are light-green or yellowing are sweeter and undesirable for use in sauces (Cantwell 2002b).

Postharvest physiology

Immature tomatillos produce ethylene at $0.5\text{--}2.0\text{ }\mu\text{g kg}^{-1}\text{ h}^{-1}$ at $10\text{--}20\text{ }^{\circ}\text{C}$, while more mature fruit

Table 135 Respiration rate of mature green tomatillos fruit (Cantwell *et al.* 1992a,b)

Temperature ($^{\circ}\text{C}$)	$\text{mg CO}_2\text{ kg}^{-1}\text{ h}^{-1}$
5	12–14
10	13–19
20	27–36

produce $1\text{--}10\text{ }\mu\text{g kg}^{-1}\text{ h}^{-1}$. Ethylene production can be high, $20\text{--}40\text{ }\mu\text{g kg}^{-1}\text{ h}^{-1}$ at $20\text{ }^{\circ}\text{C}$ in over-mature fruit. Exposure of mature fruit to ethylene caused undesirable colour changes. Respiration rates were found to remain relatively constant during storage at 5 and $10\text{ }^{\circ}\text{C}$, while rates decrease during storage at $20\text{ }^{\circ}\text{C}$ (Table 135). Respiration rates of developing fruit were about 25% higher than those of mature fruit (Cantwell *et al.* 1992a, 1992b, Cantwell 2002b). It may be climacteric since it is closely related to goldenberry (*P. peruviana*), which is a climacteric fruit (Valdenegro *et al.* 2012).

Storage

The unhusked fresh fruits can be stored in single layers in a cool, dry atmosphere for several months. Mexican and Central American people may pull up the entire plant with fruits attached and hang it upside-down in a dry place until the fruits are needed (Morton 1987). Cantwell (2002b) reported that at ambient temperatures, the husks will dry, but the fruit will remain in good condition for about 1 week. The freshness of fruit and husk can be extended by storage at $10\text{ }^{\circ}\text{C}$ with 80–90% r.h. for 1 month. Chilling injury (surface pitting and decay) occurred after 3 weeks at $5\text{ }^{\circ}\text{C}$ but no chilling injury symptoms were detected in storage at $10\text{ }^{\circ}\text{C}$.

Topee tambo

Marantaceae

Calathea allouia (Aubl.) Lindl. also referred to as *Allouya americana* (Lamk.). Other common names include allouya, Guinea arrowroot, leren, topitambo, topitambu and touple nambours. It is an herbaceous perennial bearing erect or almost erect leaves with long, grooved petioles and elongated, oval blades up to 1 m high. At the base of the plant are fibrous roots,

some of which produce clusters of round or ovoid tubers up to 6 cm long. They usually have a white or light brown thin skin and white or yellow crisp flesh, which has a pleasant nutty flavour. It is common in northern parts of South American and some of the Caribbean islands (Kay 1987). The indigenous people of tropical America probably for centuries have cultivated it and in the Brazilian Amazon may be its region of origin (Martin and Cabanillas 1976). The tuberous roots contained 13–15% starch and 6.6% proteins on the dry matter basis. There are high levels of all the amino acids, chiefly the essential ones, but only cystine deficiency had been noted and the tryptophan content had not been measured (Martin and Cabanillas 1976, Kay 1987).

Harvest maturity is some 9–12 months after planting. Harvesting is usually by hand using a garden fork (Kay 1987) or they can be harvested by simply pulling up the plants. However, in clay soils this can result in damage and the usual way is to hoe the soil carefully around the plant so as to facilitate its removal without damage. After harvesting, they may remain for up to 10 weeks in open and ventilated environments (Bueno and Weigel 1983). No other information could be found on storage. However, for propagation the rhizomes are normally stored in a cool, dry place until required for planting (Kay 1987). In spite of the marked weight loss of about 29% after 10 weeks, the best method of storing the tubers is to put them in the vegetable fibre baskets which farmers use to store roots, tubers and meal that are lined with dry leaves. Storage in special preservation units reduced weight loss but impaired the characteristics that are considered to be good for marketing (Bueno and Weigel 1983).

Turnip

Brassicaceae, Cruciferae

Brassica rapa var. *rapa* L. It probably originated in Europe and has been known from prehistoric times. It is a biennial and the edible portion is the spherical taproot and swollen hypocotyl, which is part the true root and part the cotyledons. This distinguished it from the swede (*Brassica napus* var. *napobrassica*) where both the hypocotyl and the base of the leafy stems are swollen. It is commonly purplish in colour with white flesh. The chemical content was given

Table 136 The composition of turnip for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	91.87 g	Thiamine	0.040 mg
Energy	28 kcal	Riboflavin	0.030 mg
Protein	0.90 g	Niacin	0.400 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.090 mg
Carbohydrate, by difference	6.43 g	Folate	15 µg_DFE
Total dietary fibre	1.8 g	Vitamin B-12	0.00 µg
Sugars, total	3.80 g	Vitamin A	0 µg_RAE
Calcium	30 mg	Vitamin A	0 IU
Iron	0.30 mg	Vitamin E (α-tocopherol)	0.03 mg
Magnesium	11 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	27 mg	Vitamin D	0 IU
Potassium	191 mg	Vitamin K (phylloquinone)	0.1 µg
Sodium	67 mg	Fatty acids, total saturated	0.011 g
Zinc	0.27 mg	Fatty acids, total monounsaturated	0.006 g
Total ascorbic acid	21.0 mg	Fatty acids, total polyunsaturated	0.053 g

by USDA Nutrient Database (2012a) in Table 136. Total world production in 2010 was estimated by FAO (2012) as 33,719,934 tonnes for carrots and turnips.

Harvesting and handling

Harvesting is when they have achieved an acceptable size and they can be harvested mechanically and either bunched or topped. They have a long postharvest life in cold storage and are rarely precooled. However, Holmes and Kemble (2009) recommended forced-air cooling or room cooling for turnips grown in the southern United States. Lutz and Hardenburg (1968) recommended coating with paraffin wax prior to marketing.

Storage

At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 2–3 days. The cultivar White Globe will freeze at about –1.0 to –0.5 °C (Wright 1942) or, for unspecified cultivars, –1.39 to –1.06 °C (Weichmann 1987). Refrigerated storage recommendations were as follows:

- 0 °C and 90–95% r.h. for up to 6 months (Phillips and Armstrong 1967);
- –0.6 to 0 °C (Wardlaw 1937);
- 0.6 °C and 85% r.h. (Wardlaw 1937);
- 1.1–2.8 °C (Wardlaw 1937);
- 0 °C and 90–95% r.h. for 4–5 months (Anonymous 1968, Lutz and Hardenburg 1968);
- 1–2 °C and 95% r.h. for 80–90 days (Tindall 1983);
- 0 °C and 95–100% r.h. for 60–120 days (SeaLand 1991);
- 0–1 °C and 90–95% r.h. for 4–5 months (Snowdon 1991);
- 0 °C and 95–100% r.h. for 10–14 days (turnip greens) (SeaLand 1991);
- 0 °C 95% r.h. for 4–5 months for turnips grown in the southern United States (Holmes and Kemble 2009).

Controlled atmosphere storage

Controlled atmosphere storage had a slight to no effect (SeaLand 1991). However, low O₂ in the store atmosphere was shown to reduce their respiration rate with the effect being similar at all three temperatures (Table 137).

Hypobaric storage

Onoda *et al.* (1989) found that turnips retained better appearance and lower weight loss when stored in cycles between 100 and 300 mm Hg with no humidification than those stored at a constant atmospheric pressure.

Diseases

Fatima *et al.* (2009) found *Fusarium* sp., *Geotrichum candidum* and *Cladosporium cladosporioides* infecting turnips in on the market in Karachi, Pakistan, with *Fusarium* sp. the most common.

Table 137 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of bunching turnips with leaves (source: adapted from Robinson *et al.* 1975)

°C	0	5	10	15	20
In air	15	17	30	43	52
In 3% O ₂	10		19		39

Turnip greens

These are the leaves of the turnip, which may be used like spinach and are called turnip greens. Top icing is recommended to keep them fresh (Lutz and Hardenburg 1968). Refrigerated storage recommendations were as follows:

- 0–1.1 °C (Wardlaw 1937);
- 0 °C and 90–95% r.h. (Lutz and Hardenburg 1968);
- 0 °C and 95–100% r.h. for 10–14 days (SeaLand 1991).

Turnip rooted chervil

Umbelliferae

Chaerophyllum bulbosum L. Other common names include tuberous rooted chervil, bulbous chervil and parsnip chervil. It is native of southern Europe and western Asia. A biennial or annual herb growing up to 1.2 m high with divided leaves and large umbels of white flowers. It is cultivated on a small scale in parts of Europe for the edible swollen roots that are grey to black with sweetish yellow flesh. The tuberous roots are stored for a period after harvest to facilitate starch hydrolysis, which improves their eating quality. It can take several months but Geoffriau *et al.* (2005) found that β-amylase activity was induced by low temperature and was responsible for the early starch hydrolysis.

Turnip rooted parsley

Umbelliferae

Petroselinum crispum var. *tuberosum*, also called Hamburg parsley. Its origin has not been identified but it may have been in Germany as one of the common names suggests. The edible portion is the off white coloured tap root, which resembles a small parsnip but has a flavour similar to celeriac. The leaves resemble flat-leafed parsley and can be used as an herb. At room temperature of 20 °C and 60% r.h. it was reported in Mercantilia (1989) that they could be kept for about 1 week. Refrigerated storage recommendations were as follows:

- 0 °C and 90–95% r.h. for 1–2 months (Lutz and Hardenburg 1968);

- 0–1 °C and 85–90% r.h. for 1–2 weeks (Amezquita Garcia 1973);
- 0 °C and 95–100% r.h. for 2–2.5 months (Hardenburg *et al.* 1990);
- 0 °C and 95% r.h. for 4–6 months (Mercantilia 1989);
- 0 °C and 95–100% r.h. for 30–60 days (SeaLand 1991).

Controlled atmosphere storage with 11% CO₂ and 10% O₂ helped to retain the green colour of the leaves of *P. crispum* during storage (Hardenburg *et al.* 1990).

Ullucu

Basellaceae

Ullucus tuberosus Caldas, other common names include ulluco and ulluco. They are an important food of the high Andes of South America. It was reported to have been grown in England by the Horticultural Society of London in the latter part of the 19th century (Harrison *et al.* 1985). It is a perennial herb. They produce tubers at the end of slender rhizomes or adventitious roots, which are spherical or cylindrical in shape and usually with a yellow skin, but it can also be purple, brown, red, pink or white. The flesh is yellow and mucilaginous. It is a potato-like tuber that is rich in ascorbic acid and has a silky texture and nutty taste (Popenoe 1992).

In a study of four Andean root crops (*Solanum* sp., *Tropaeolum tuberosum*, *Oxalis tuberosa* and *Ullucus tuberosus*) Campos *et al.* (2006) found that the content of bioactive compounds was high and variable between crops and within the genotypes studied. The antioxidant capacity within the four crops studied varied from 483 to 9800 µg trolox equivalent g⁻¹, phenolics ranged from 0.41 to 3.37 mg chlorogenic acid equivalent g⁻¹, anthocyanins ranged from 0.08 to 2.05 mg cyanidin 3-glucoside g⁻¹ and carotenoids ranged from 1 to 25 µg β-carotene g⁻¹. Ulluco was the only crop that contained betalains in the acid form of betaxanthins (22–96 µg g⁻¹) and betacyanins (64 µg g⁻¹) with no presence of carotenoids or anthocyanins. The overall average moisture content of the 15 genotypes studied, supplied by the International Potato Center, was 86.7 ± 1.7%. They are usually consumed directly after harvest and are rarely stored (Kay 1987).

Wasabi

Brassicaceae, Cruciferae

Wasabia japonica (Miq.) Matsum, also called Japanese horseradish. It is a perennial plant native to Japan that has been cultivated there for more than a thousand years and is now being cultivated in many countries. Wasabi can be grown in two main ways, either in flooded fields or in soil-based media (Sultana and Savage 2008). The unique flavour of wasabi comes from isothiocyanates which evolve from precursor glucosinolates by the enzyme myrosinase when the tissue is disrupted. Isothiocyanates found in wasabi are volatile, possess strong pungent smells and are toxic at high intakes. The overall flavour of wasabi depends on individual isothiocyanate content. Allyl isothiocyanates are found in the highest concentration in all tissues, ranging from 86 to 92% of the total isothiocyanate content. Apart from flavouring sauces and foods wasabi isothiocyanates have some anti-cancer effects and they can also counter inflammatory conditions such as asthma and anaphylaxis. Isothiocyanates have also been shown to inhibit platelet aggregation in the blood. Wasabi is a valuable crop that can be processed into a tasty condiment. It was predicted that its production and consumption will increase as it becomes more appreciated in western cuisine (Sultana and Savage 2008).

Water chestnut

Lythraceae, Trapaceae

Trapa natans L. var. *bispinosa* (Roxb.) Makino, *Lythrum salicaria* L. also called singhara and water caltrop. Karg (2006) reported that remains of water chestnut were detected in southern Germany dated to between the 4th and 1st centuries BCE. She also reported that until recently the starch-containing nuts were used for human nutrition in Europe. *T. natans* is the only European species of the genus and until recently it grew and was even cultivated, in many suitable water bodies, for human food, but it is now a rare plant. The oldest written source from Roman times describes the making of bread from water chestnut seeds by the Thracians (Plinius Historia Naturalis 22, 27 quoted by Karg 2006). Currently water chestnut can be found only in some remote

lakes and protected nature reserves in Europe. In China water chestnut has been an important food and especially as prayer offerings at least since the 2nd century BCE. In India it is widely cultivated in fresh water lakes for the fruits that are eaten raw, milled into flour or boiled (Singh *et al.* 2010). In parts of North America water chestnut is an invasive non-native species with a floating rosette of leaves spreading rapidly forming a dense canopy that can impede navigation and can have a substantial impact on native species of submerged grasses by blocking sunlight from reaching the sediment surface (Mullin 1998).

It is an annual aquatic plant whose fruits overwinter at the bottom of the water bodies and in Europe germinates in early spring. A thin stalk with compound roots grows up to the water surface where floating leaves develop. One stem can create up to 10 leaf rosettes which float on the water surface as a carpet. The inconspicuous white flowers are produced in the leaf axils with the fruits developing at the basal parts of the rosettes in late summer. Until 1880s it was possible to buy water chestnuts at many markets all over Europe. At many places in Europe water chestnuts were known and used for human food until the beginning of the 20th century (Brockmann-Jerosch 1914, quoted by Karg 2006). The thorny fruits contain one white seed the size of a hazelnut that contains about 50% starch and 10% protein.

Singh *et al.* (2010) analysed the composition of fresh water chestnut kernels in India with means (standard deviation) of triplicate analysis on a fresh weight basis in gram per 100 g. They reported 81.12 ± 0.5 water, 1.27 ± 0.02 reducing sugars, 4.36 ± 0.03 non-reducing sugars, 1.87 ± 0.03 total proteins, 0.142 ± 0.03 total acidity, 0.36 ± 0.02 crude lipids, 1.33 ± 0.04 total ash, 0.72 ± 0.02 crude fibre and $7.2 \pm 0.2\%$ TSS. Water chestnut is believed to suppress stomach and heart burning. Samples kept at room temperature were completely dried out after 90 days but did not show any subsequent decrease in weight. Those stored at 4°C were completely dried out after 120 days while the samples stored submerged in water started decaying after the first 10 days and were completely decayed in 40 days. Frozen samples retained their eating quality in good condition for up to 1 year (Singh *et al.* 2010).

Watercress

Cruciferae

There are two main *Nasturtium* spp. green watercress is *N. officinale* that is frost susceptible, but remains green until the first frosts, and winter or brown watercress, which is the hybrid *N. microphyllum* $\times$ *officinale*, which turns purple or brown in autumn and is less susceptible to frost damage. Both are also simply called cress. The edible portion is the leaves and stems that are used in salads. It has been gathered from the wild for centuries in Britain where it grows along the sides of streams and it is mostly cultivated in clear running water. The chemical content was given by USDA Nutrient Database (2012a) in Table 138.

Harvesting and handling

It is cut while it is still tender and young. Yellow and necrotic leaves are discarded and it is commonly tied in bunches and placed in split wooded baskets or plastic trays. Expanded polystyrene boxes have been used for many years for non-returnable transport of trays of watercress (Figure 57). Forced-air cooling with high humidity and vacuum cooling were the

Table 138 The composition of watercress for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.40 g	Thiamine	0.080 mg
Energy	32 kcal	Riboflavin	0.260 mg
Protein	2.60 g	Niacin	1.000 mg
Total lipid (fat)	0.70 g	Vitamin B-6	0.247 mg
Carbohydrate, by difference	5.50 g	Folate	80 µg_DFE
Total dietary fibre	1.1 g	Vitamin B-12	0.00 µg
Sugars, total	4.40 g	Vitamin A	346 µg_RAE
Calcium	81 mg	Vitamin A	6917 IU
Iron	1.30 mg	Vitamin E (α-tocopherol)	0.70 mg
Magnesium	38 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	76 mg	Vitamin D	0 IU
Potassium	606 mg	Vitamin K (phyloquinone)	541.9 µg
Sodium	14 mg	Fatty acids, total saturated	0.023 g
Zinc	0.23 mg	Fatty acids, total monounsaturated	0.239 g
Total ascorbic acid	69.0 mg	Fatty acids, total polyunsaturated	0.228 g

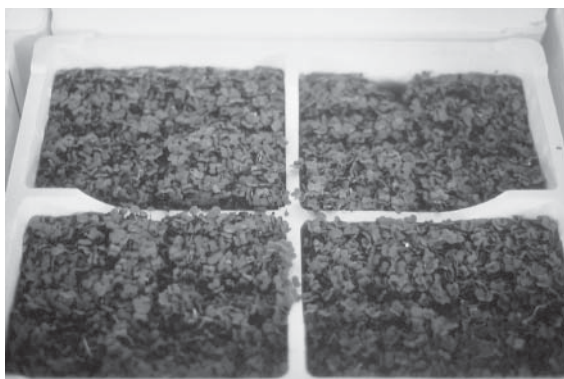


Figure 57 Cress packed in expanded polystyrene boxes in the wholesale market in the United Kingdom.

most acceptable, air cooling in a conventional cold store was suitable and hydrocooling was said to be not suitable (MAFF n.d.). This latter statement is surprising and also contradicts Fidler (1963), who stated that watercress is usually hydrocooled. Top icing is also used (Lutz and Hardenburg 1968) and vacuum pre-cooling was recommended by Aharoni *et al.* (1989).

Storage

The factors which limit storage are wilting, yellowing and bacterial rots. After 5 days of storage in air there was 25% yellowing at 5 °C and 100% yellowing at 15 °C. 1-MCP applied at 500 or 1000 nL L⁻¹ for 8 h at 10 °C had no significant effect on the storage life of watercress stored at 5 or 15 °C. It was concluded that watercress could be stored for a maximum of 4 days at 5 °C (Bron *et al.* 2005). Other refrigerated storage recommendations were as follows:

- 0.6–1.7 °C and 80–82% r.h. (Wardlaw 1937);
- 0–1.7 °C and 90–95% r.h. for up to 3 or 4 days (Lutz and Hardenburg 1968);
- 0–2 °C for up to 7 days (Tindall 1983);
- 0 °C and 95–100% r.h. for 4–7 days (SeaLand 1991);
- 0–1 °C and 95–100% r.h. for 3–4 days for watercress (Snowdon 1991);
- 0–1 °C and 95–100% r.h. for 1–2 weeks for cress (Snowdon 1991).

Table 139 Effects of temperature and reduced O₂ level on the respiration rate (CO₂ production in mg kg⁻¹ h⁻¹) of watercress (source: adapted from Robinson *et al.* 1975)

Temperature (°C)	0	5	10	15	20
In air	18	36	80	136	207
In 3% O ₂	19	–	72	–	168

Controlled atmosphere storage

Low O₂ in the store atmosphere was shown to reduce their respiration rate at the higher temperature (Table 139). The fact that O₂ had no effect at the optimum storage temperature of 0 °C could indicate that it is not an appropriate technique for watercress. In experiments by Aharoni *et al.* (1989) chlorophyll degradation was delayed effectively with 5% CO₂ in air in a flow-through system.

Hypobaric storage

Hypobaric storage at 3 °C and 75 mm Hg for 12 days retained ascorbic acid content better than storage in atmospheric pressure and retained its protein and chlorophyll content better (Bangerth 1974).

Transport

Aharoni *et al.* (1989) studied freshly harvested watercress under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in sealed polyethylene lined cartons resulted in a marked retardation of both yellowing and decay. However, sealed film packaging was applicable only if the temperature during transit and storage was well controlled; otherwise, perforated polyethylene was better.

Water spinach

Convolvulaceae

Ipomea reptans Poir., *I. aquatica* Forsk., other common names include tong cai and kang kong. As the name implies it is a floating aquatic herbaceous perennial cultivated throughout Asia. The young terminal shoots and leaves are used as spinach. It is also used as an animal feed (Purseglove 1968). The

shoots are washed after harvest and tied in bundles of 8–10 shoots. They can be packed in banana leaves or polyethylene-lined crates to prevent wilting (Tindall 1983).

Welsh onion

Alliaceae, Liliaceae

Allium fistulosum L. also called Japanese bunching onion and ciboule. It probably originated in eastern Asia where it has been cultivated in China and Japan since prehistoric times. It has upright hollow cylindrical leaves up to about 50 cm high with a globose head of pale yellow flowers. It produces bulbs that are only slightly swollen. The chemical content was given by USDA Nutrient Database (2012a) in Table 140.

White yam

Dioscoreaceae

Dioscorea rotundata Poir. Okeke (2004) investigated the taxonomic position of *D. cayenensis*, *D. rotundata* and *D. pruinosa* and found diagnostic characteristics that were more than enough to warrant the recognition of each as separate species (Table 149). This view is supported by hybridization experiments, which indicated that members of the group are almost completely inter-sterile. Other common names include negro yam, Guinea yam, white Guinea yam, eboe yam, 8 months yam, name blanco, Portuguese yam and proper yam.

D. rotundata is believed to be indigenous to the area of West Africa stretching from Côte d'Ivoire to Cameroon and is generally considered to be the best edible yam in that region (Coursey 1968). The edible portion is the tuber, which is normally cylindrical, but can be palmate. They have brown skin and white flesh and normally weigh around 2–5 kg but can be as much as 25 kg. The plants grow vigorously and can climb to a height of 10–12 m. The stems are cylindrical or slightly striated and are usually spiny, though sometimes completely smooth. The leaves are narrowly ovate, but can vary from deeply cordate to almost orbicular, and are 4–20 cm long, opposite or alternate. Some varieties have purplish leaf veins and stems. Male flowers are small and borne on spikes

Table 140 The composition of welsh onion for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	90.50 g	Thiamine	0.050 mg
Energy	34 kcal	Riboflavin	0.090 mg
Protein	1.90 g	Niacin	0.400 mg
Total lipid (fat)	0.40 g	Vitamin B-6	0.072 mg
Carbohydrate, by difference	6.50 g	Folate	16 µg_DFE
Total dietary fibre	2.4 g	Vitamin B-12	0.00 µg
Sugars, total	2.18 g	Vitamin A	1160 IU
Calcium	18 mg	Vitamin E (α-tocopherol)	0.51 mg
Iron	1.22 mg	Vitamin D (D2 + D3)	0.0 µg
Magnesium	23 mg	Vitamin D	0 IU
Phosphorus	49 mg	Vitamin K (phylloquinone)	193.4 µg
Potassium	212 mg	Fatty acids, total saturated	0.067 g
Sodium	17 mg	Fatty acids, total monounsaturated	0.056 g
Zinc	0.52 mg	Fatty acids, total polyunsaturated	0.156 g
Total ascorbic acid	27.0 mg		

while female flowers and the production of seeds is rare (Martin and Sadik 1977, Kay 1987).

Opara (1999) reported that the content of the tubers per 100 g was water 80 g, carbohydrate 16 g, protein 1.5 g and fibre 0.5–0.6 g. Knoth (1993) gave the following analysis on a fresh weight basis: 58–80% moisture, 15–23% carbohydrates, 0.1–0.2% fats and 1.1–2.0% crude protein. Osunde and Orhevba (2009) found that during storage in barns in Nigeria there is reduction in crude protein (as high as 30–50%), starch and mineral content while fibre and sugar levels and increased as high as 38–49% for sugars. Osunde (2008) showed that tubers that had been stored for 150 days in traditional barns were preferred by a sensory evaluation panel to those that had been freshly harvested. In Côte d'Ivoire Kouakou Dje *et al.* (2010) stored tubers of *D. alata* and *D. cayenensis-rotundata* for 6 months in a ventilated store where the conditions were 26.56 ± 3 °C and 82 ± 5% r.h. The total phenolic content varied in different parts of the tuber and decreased during storage. Protein content was 7.90–7.94% and generally did not vary significantly during storage although a slight fall was observed in the distal part of one variety after 6 months. Lipids were low, only about

0.20% of the dry matter and did not vary significantly during storage. Weight loss was 31% due to sprouting and dehydration after 110 days of storage under ambient conditions in the *D. rotundata* cultivar Oshei. Also the starch content decreased by approximately 3.5–4.5 g 100 g⁻¹ while sugar and fibre levels increased slightly (Afoakwa and Sefa-Dedeh 2001).

Harvesting and handling

Harvesting is usually about 7–9 months after planting when the vines die down (Purseglove 1972, Martin and Sadik 1977, Kay 1987). Harvesting is by hand, but some success has been achieved with mechanical harvesting for plants grown on high ridges (Kay 1987).

Harvest or postharvest damage can result in rapid deterioration. In tubers that are cut in two or deeply cut their respiration rate rises rapidly and there is an induction or increase in activity of certain enzymes, notably amylase and acid invertase. Invertase activity is highest in the layers of cells adjacent to the wound and also develops in the region where periderm forms. Concomitantly, there is a mobilization of food reserves resulting in an increase in reducing and non-reducing sugars in the wound tissue (Passam *et al.* 1977). Physical injury during postharvest handling of yams is common in Jamaica. Cutting off the 'head' end of the tuber at harvest, either for retention as planting material or because this portion is inedible, is common practice and can lead to higher postharvest losses (Table 141).

Curing

Curing was first described for potatoes (*Solanum tuberosum*) by Priestley and Woffenden (1923) and

Table 141 Effects of cutting off the head end of the tuber at harvest on the weight loss of *Dioscorea rotundata* tubers during storage in Jamaican ambient conditions (source: adapted from Thompson 1972b)

	Days in storage		
	12	25	34
Cut	9.8	16.8	22.6
Not cut	7.1	11.8	16.5

The mean fungal score over that storage period was 1.9 for cut tubers and 0.9 for those not cut where 0 = none and 5 = maximum.

sweetpotatoes (*Ipomea batatas*) by Artschwager and Starrett (1931). Both are dicotyledons and yams are monocotyledons. Cambium tissue is common in the stems and roots of dicotyledons but rare in monocotyledons. Certain palms, which are monocotyledons, produce cambia in the stems but this is unusual. Therefore experiments carried out in Jamaica in the early 1970s were somewhat speculative and the spectacular results were surprising (Thompson 1972a). The curing process is to form a layer of starch at the cut surface within a few hours, then a suberized layer and finally a cork cambium (periderm) in a similar way to that reported for potatoes (Figure 58) (Been *et al.* 1976). There were considerable differences in the thickness of the periderm especially in those that had been cured in full sunlight that produced a very thick periderm (Figure 59). Passam *et al.* (1977) also showed that the success of curing does not rely solely on the formation of suberin and periderm but relates to the integrity and moisture content of the surface starch layer.

Cured tubers had a lower weight loss throughout storage compared to those that had not been cured. However, cured tubers sprouted earlier by about 2 weeks when stored at tropical ambient temperatures, probably due to the increased cambial activity associated with curing. Weight loss of *D. rotundata* was considerably reduced when they were cured (Figure 60

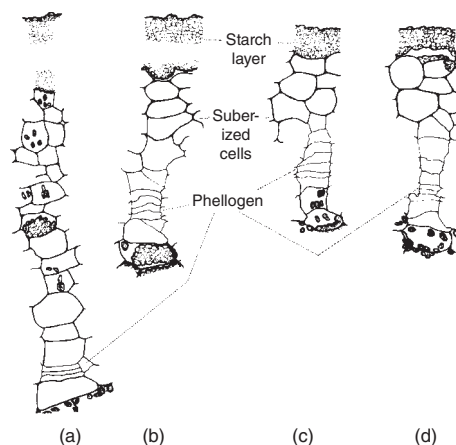


Figure 58 Sections through the cut surfaces of yam tubers after 7 days of curing and 8 days of subsequent storage. Curing conditions were (a) direct sunlight, (b) 26 °C and 66% r.h., (c) 30 °C and 91% r.h. and (d) 40 °C and 98% r.h.

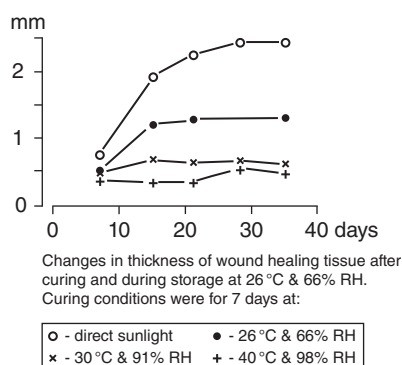


Figure 59 Effects of curing yams on the thickness of wound healing.

and Table 142) and 14% of the tuber surface was covered with mould after 75 days of storage compared with zero for those that had been cured. Curing also reduced the necrotic tissue from 8 to only 2%. The reduction in weight loss due to curing was effective whether the tubers were stored in Jamaican ambient conditions of cold storage (Figure 61). Ikeemobi *et al.* (1986) showed that lipolytic acyl hydrolase activity decreased in the tuber after wounding and disappeared by the fourth day. However, there were 2–9 times increased activity of lipoxygenase peroxidase and PPO with maximum values on the fourth and fifth days, respectively, after wounding. Lipoxygenase and PPO activities measured in the proximal half of tubers were much higher than corresponding activities in the distal half.

Exposure of the tubers to 35–40 °C and 95–100% r.h. for 24 h was found to initiate the curing process (Thompson 1972a). Passam *et al.* (1977) found that suberization occurred at 17 °C in 4–5 days, at 25 °C in 3–4 days and at 35 °C in 2 days and that periderm formation occurred at 17 °C in greater than 10 days at 25 °C in 5 days and at 35 °C in 4 days. H.J. Passam (unpublished) reported that *D. rotundata*

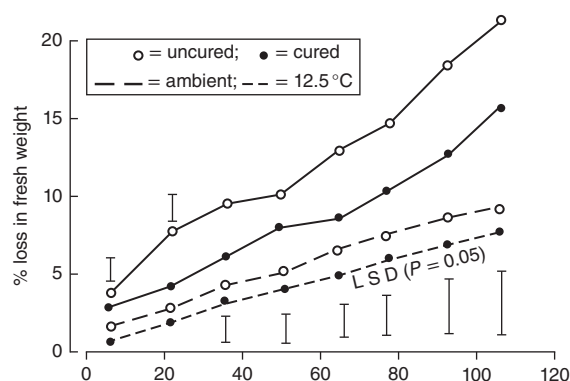


Figure 60 Yam effects of curing and storage conditions on weight loss during storage of *D. rotundata* in Jamaica.

grown in Greece are cured routinely at about 35 °C and 85–90% r.h. and their storage life was 5–6 months. Nnodu (1986) recommended 26 °C and 92% r.h. for 11–15 days. Adesuyi (1973) recommended 25–30 °C and 90% r.h. for 5 days.

When applied commercially in Jamaica there were problems of bacterial soft rots developing during subsequent storage. Loading the tubers into the curing room, heating them until the surface of the tubers reached 40 °C and then injecting the steam to increase the humidity overcame these problems. Tubers cured in this way had reduced weight loss, no fungal infection, no necrotic tissue and no bacterial rots after storage (Cecil, Been and Thompson unpublished).

Storage

In tropical ambient conditions Kay (1987) indicated that sound tubers can be stored for up to 4 months, but desiccation and sprouting could be problems. In Nigeria yams are stored in specially constructed barns (Figures 62 and 63). In a comparison between barn

Table 142 Effects of curing and storage temperature on fresh weight loss, fungal score, where 0 = none and 5 = maximum and necrotic tissue of *Dioscorea rotundata* during 127 days of storage (source: adapted from Thompson 1972b)

Storage conditions	Weight loss (%)		Fungal score		Necrotic tissue	
	Not cured	Cured	Not cured	Cured	Not cured	Cured
Ambient	23.3	17.9	0.0	0.0	4	3
13 °C	9.8	8.0	1.4	1.2	9	10

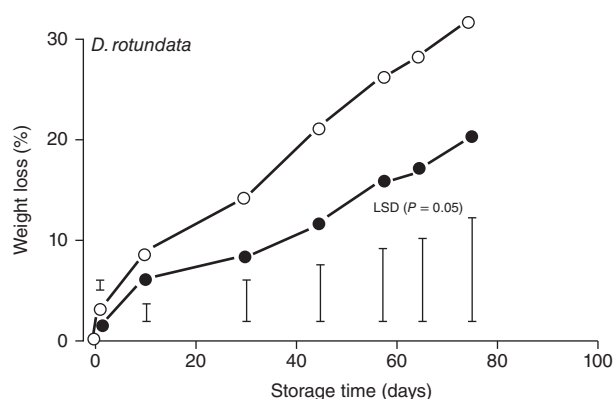


Figure 61 Effects of curing on the percentage fresh weight loss of *D. rotundata* in Jamaican ambient storage.



Figure 62 Yam barn in Nigeria showing the construction using live branches that produce leaves to provide a shaded humid environment.

storage and pit storage for yams in Nigeria, Ezeike (1985) recorded weight losses over a 5-month period of 60% for the former method but only 15–25% for the latter. Yams stored in slatted wooden trays in the coastal region of Cameroon had losses of 29–47% in only 2 months (Lyonga 1985). Refrigerated storage recommendations include 16 °C and 80% r.h. for several months (Tindall 1983). Osunde and Orhevba (2011) stored *D. rotundata* in traditional yam barns in Nigeria for 5 months. The barns were erected in the open air, where sufficient shade and ventilation were available. One barn had intermittent forced-air flow using a fan and half the tubers in barn had been treated by soaking them in water-containing neem bark for 12 h the other half were soaked in water. The temperature in the barn with fan was slightly lower



Figure 63 Detail of how yam tubers are tied to the upright poles in a Nigerian yam barn.

than that of the barn without fan. Tubers stored in the barn with fan had the least sprout weight and least weight loss. The temperature in the barn with fan fluctuated between 20 and 36 °C with an average of 29 °C while that in the barn without fan fluctuated between 23 and 38 °C, with an average of 33 °C over the storage period. The humidity in the barn with fan

ranged between 26.5 and 60.4% r.h. with an average of 38% r.h. while that in the barn without fan ranged between 23 and 55% r.h. with an average of 44% r.h. over the storage period. There was an average of 7% less sprout weight in the barn with fan. Opara (1999) reported that the optimum conditions for storage of what is referred to as *White yam* and *Guinea yam* were 16 °C and 80% r.h. for several months.

Chilling injury

At 1.1 °C total physiological breakdown occurred within 10 days and chilling injury was observed on tubers stored at 12.5 °C (Coursey 1968). In later work tubers stored at 11.7 °C kept in better condition than those stored in tropical ambient conditions. However, when the storage period exceeded 1 week, the tubers lost weight rapidly and the rate was increased as the exposure time to 11.7 °C increased (Figure 64). They also became soft, necrotic and infected with fungi shortly after removal to higher temperatures. This confirms Coursey's findings on chilling injury (Thompson 1972b, Thompson *et al.* 1977a). When tubers were stored at 13, 15, 17 or 19 °C

those stored at 13 °C quickly developed symptoms on fungal infection while those stored at 15 °C developed symptoms later but before those stored at higher temperatures (Figure 65). This probably means that chilling injury can develop even at 15 °C after prolonged exposure.

Respiration rate

Respiratory activity is minimal during the period of dormancy. Rates of respiration varied from 5 to 20 ml CO₂ kg⁻¹ h⁻¹ f.w. in healthy tubers to over 35 ml CO₂ kg⁻¹ h⁻¹ f.w. in decaying tubers. Respiratory weight loss contributes significantly to total storage loss and yams stored for 5 months may lose up to 10% of dry matter content through respiration (Coursey 1967). Also Passam *et al.* (1978) showed that at harvest the rate of respiration was high: 15 ml CO₂ kg fresh weight⁻¹ h⁻¹ at 25 °C and 29 ml kg fresh weight⁻¹ h⁻¹ at 35 °C. However, as the tubers entered dormancy this rate declined to low levels of 3 ml CO₂ kg fresh weight⁻¹ h⁻¹ at 25 °C and 8 ml kg fresh weight⁻¹ h⁻¹ at 35 °C. The respiration rate then increased again at breakage of dormancy to over 20 ml CO₂ kg fresh weight⁻¹ h⁻¹.

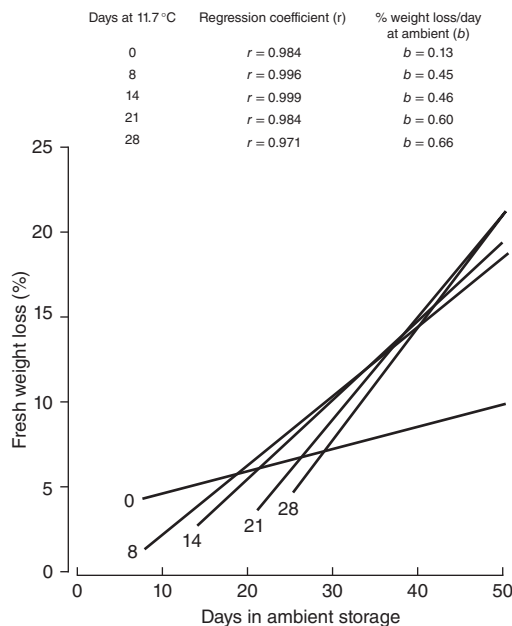


Figure 64 Effects of days in storage at 11.7 °C prior to removal to Jamaican ambient conditions on the weight loss of *D. rotundata*.

Sprouting

Dormancy and sprouting are affected by the maturity of the tubers at harvest as well as the postharvest conditions. In ambient conditions in Jamaica sprouting could occur after only 4 weeks (Thompson 1972b) while in Nigerian ambient conditions sprouting occurred within 8 weeks (Coursey 1961). Passam (1982) and Opara (1999) reported the dormancy period of *D. rotundata* from Nigeria as 12–14 weeks. In India tubers of the cultivars Sree Latha stored at room temperature of 30–32 °C and 80–85% r.h. in the dark sprouted 70–80 days after harvest. In the apical and basal regions, the starch content decreased while the sugars and α -amylase activity increased (Muthukumarasamy and Panneerselvam 2000). Ile *et al.* (2006) described three phases that occur during the storage of *D. rotundata*. The first phase is when the tuber is dormant and does not sprout whatever the storage conditions. The second phase is when the meristem starts to form in the parenchyma tissue just below the tuber's periderm. The third phase is when the tuber sprouts. They postulate that sprout

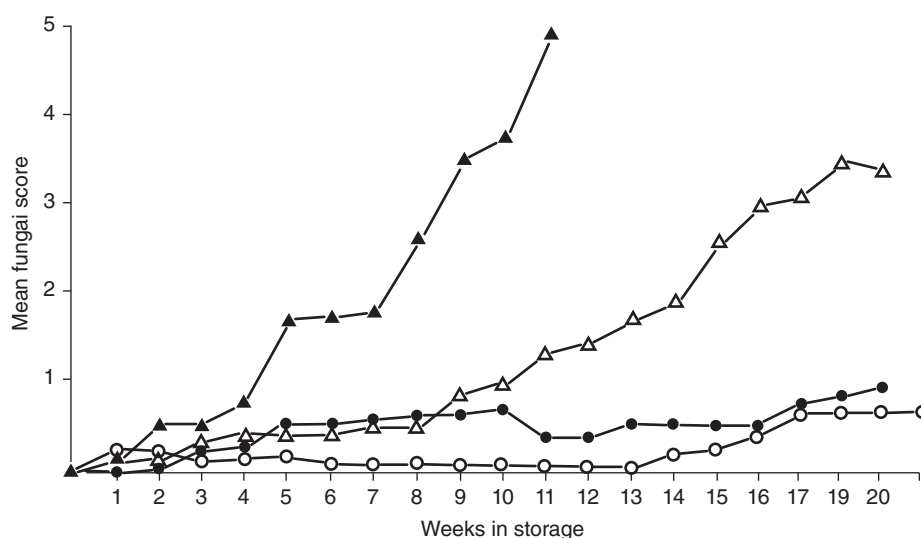


Figure 65 Effects of temperature of the development of mould on the surface of yams during storage: ○ = 19°C, ● = 17°C, △ = 15°C and ▲ = 13°C (mean score where 0 = none and 5 = surface entirely covered).

suppressants can only act on *D. rotundata* after the start of phase two.

Irradiation at doses of between 7.5 and 15 krad inhibited sprouting of *D. rotundata* during 6 months storage without inducing adverse changes in acceptability or physiological properties (Vasudevan and Jos 1992). They also reported differences in varietal responses to γ -irradiation. Osunde (2008) reported that an average dose of 120 Gy and a dose rate of 114 Gy h⁻¹ were applied to the cultivar Asana and stored for 6 months in a barn or on the ground; results showed that irradiation reduced sprouting in both storage types. However, there was less rotting in the non-irradiated yams stored on the ground than the irradiated ones. Also food products made from irradiated yams were judged to be better in quality than those made from the non-irradiated ones (Vasudevan and Jos 1992).

In contrast to *Solanum tuberosum* the tubers are stem tissue and therefore sprout suppressants such as CIPC (chloroisopropyl phenylcarbamate) affect them as soon as they are placed in storage. A proprietary potato sprout suppressant containing CIPC and IPC in a dust formulation had no effects on sprouting. Low-temperature storage can control sprouting. No sprouting occurred on any tubers at 13°C during

5 months of storage, but there was chilling injury at temperatures below 15°C when stored for over a month (Thompson *et al.* 1973a) so this method was not appropriate. Orhevba and Osunde (2006) reported that CIPC did not have any effect on *D. rotundata* tubers.

Tschannen (2003) reported that gibberillic acid applied to *D. rotundata* directly after harvest prolonged dormancy by 9–11 weeks and reduced respiration rate at the time of sprouting. Osunde and Orhevba (2011) reported that tubers treated with either neem slurry or neem bark extract had less sprouting than those not treated. The effect of maleic hydrazide in controlling sprouting in yam showed that soaking the tubers in 1000 µL L⁻¹ solutions for 10 h before storage reduced the rate of sprouting by 8% (Ramanujam and Nair 1982). However, Osunde (2008) reported that maleic hydrazide was not effective in inhibiting sprouting in *D. rotundata* tubers. Nonanol placed inside polyethylene bags with tubers reduced and delayed sprouting but increased the level of flesh necrosis. Thompson (1972b) concluded that the only way of preventing sprouting when yams are stored beyond their normal dormancy was to use cold storage just above the temperature that will cause chilling injury.

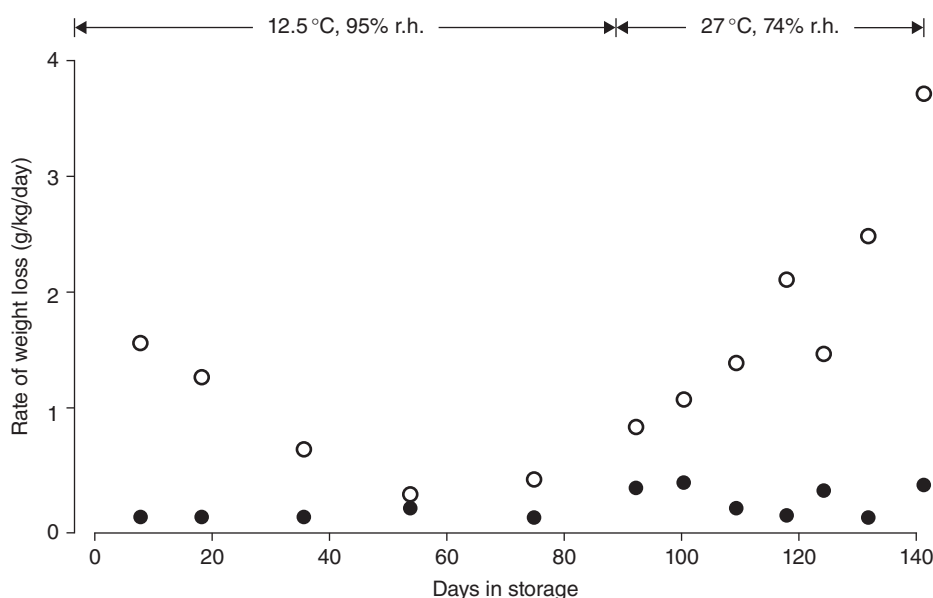


Figure 66 Storage loss rate ($\text{g kg}^{-1} \text{ day}^{-1}$) of *D. rotundata* tubers that were stored either in 37.5μ polyethylene bags (●) or not in bags (○).

Modified atmosphere packaging

Cured tubers were dipped in $500 \mu\text{L}^{-1}$ thiabendazole, dried and individually sealed in 0.04 mm thick polyethylene film. During storage for 5 months at $12\text{--}13^\circ\text{C}$ tubers lost only 3% in weight, did not sprout, had no internal necrosis and had no surface lenticel proliferation (Thompson 1972b). This latter effect has previously been shown to occur on plastic wrapped yam tubers in ambient temperatures and can be seen as small white dots on the tuber surface. All the tubers removed from storage to ambient conditions sprouted within 3 weeks. In storage at 12.5°C the rate of weight loss progressively decreased up to about 60 days then there was some indication of a slight increase in the rate, but when they were removed to ambient conditions after 90 days the rate progressively increased rapidly. This coincided with sprouting so the increased rate would be a combination of sprouting and the changes in temperature and humidity. However, tubers in polyethylene bags had a low constant rate of weight loss throughout storage at both 12.5°C and ambient conditions even though the yams inside the bags still began sprouting when they were removed to ambient conditions (Figure 66).

Diseases

Yam tubers are traditionally dusted with wood ash or sometimes lime (calcium hydroxide) directly after harvesting by small-scale farmers in Nigeria to reduce subsequent storage rots (Coursey 1961). Similar treatment was also reported by farmers in Jamaica (Thompson 1972b). Tubers were treated with either calcium oxide or local gin (fermented palm wine or sap from *Elaeis guineensis*) by Ogali *et al.* (1991) and stored at $25\text{--}32^\circ\text{C}$ with 62–90% r.h. for 32 weeks. After 24 weeks the tubers that had been treated with gin showed no rotting, while 22.5% of the lime-treated yams were rotten. After 32 weeks, the level of rotting was comparable in all treatments. Four species were isolated from the tubers, *Aspergillus niger*, *Fusarium oxysporum* and *Penicillium citrinum*, all of which were found to be mildly pathogenic, and *Fusarium moniliforme* [*Gibberella fujikuroi*] which did not produce any rot symptoms. Postharvest dipping in a benzimidazole fungicide effectively controlled storage rots (Thompson 1972b) but its use is now restricted in many countries (Figure 67). Tubers of the cultivar Iyawo inoculated by spraying with conidiospore suspension of *Trichoderma viride* in potato dextrose broth showed a drastic reduction

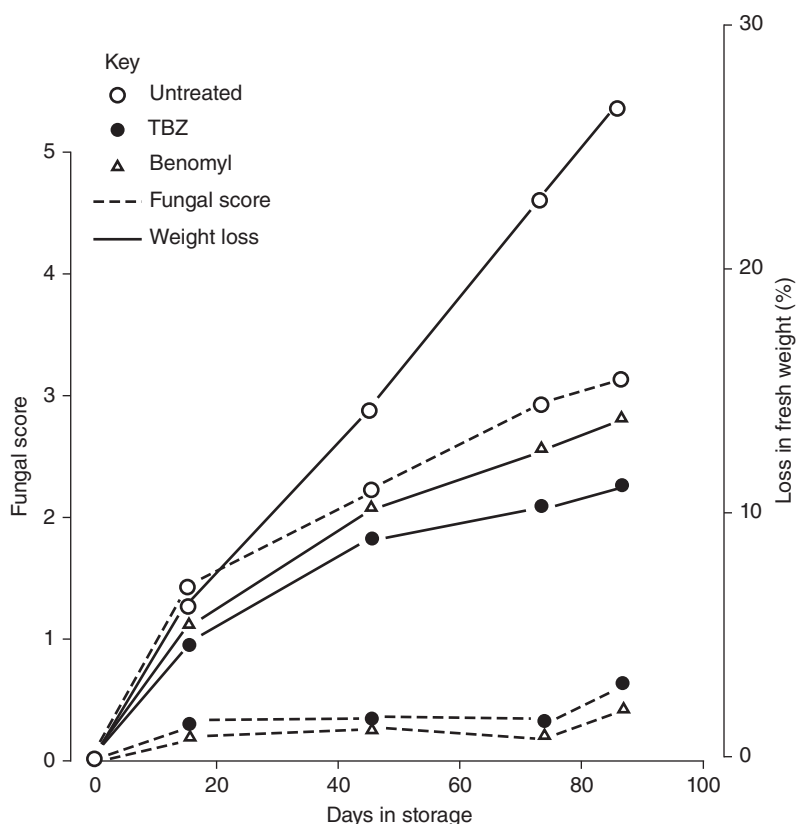


Figure 67 Effects of fungicides of the surface fungi (mean score where 0 = none and 5 = surface entirely covered) and weight loss during storage of *Dioscorea rotundata* at 12.5 °C and 95% r.h.

in the range and number of mycoflora, including the pathogens *Rhizopus* sp., *Rhizoctonia* sp., *Aspergillus niger*, *A. flavus*, *Penicillium oxalicum*, *Botryodiplodia theobromae*, *Fusarium oxysporum*, *F. solani*, *Neurospora* sp. and *Choanephora* sp., on the tuber surface during 5 months of storage in a traditional yam barn in Nigeria (Okigbo and Ikediugwu 2001).

Aboagye-Nuamah *et al.* (2005) collected *D. rotundata* tubers from a yam barn and selected markets in Accra, Ghana, to identify the most predominant pathogens associated with the rots. Nine fungal spoilage microorganisms, including *Aspergillus flavus*, *Aspergillus niger*, *Botryodiplodia theobromae*, *Fusarium culmorum*, *Fusarium oxysporum*, *Fusarium* sp., *Penicillium brevi-compactum*, *Penicillium* sp. and *Rhizopus stolonifer* and a bacterium species *Erwinia carotovora*, were identified. The mean incidence of occurrence of the organisms on

rotten tissues ranged from 1.2 to 28.5%. Of the 10 micro-organisms isolated, *B. theobromae*, *F. oxysporum* and *R. stolonifer* were the most frequently encountered spoilage microorganisms in the markets. *E. carotovora*, *Fusarium solani* and *Penicillium* sp. were relatively sparse (incidence not exceeding 3%) compared to the other yam spoilage microorganisms. Although there was generally no significant difference in the severity of rots induced by the different microorganisms in the tubers, *R. stolonifer* commonly induced more rot in the zones of the tubers compared to *B. theobromae* and *F. oxysporum*. Yusuf and Okusanya (2008) found *R. stolonifer*, *Penicillium oxalicum* and *A. niger* on *D. rotundata* on the Yola markets in Nigeria. The mean percentage incidence was 45% for *R. stolonifer*, 38% for *A. niger* and 22% for *P. oxalicum*. The optimum temperature for growth of the three isolates was the same at 35 °C,

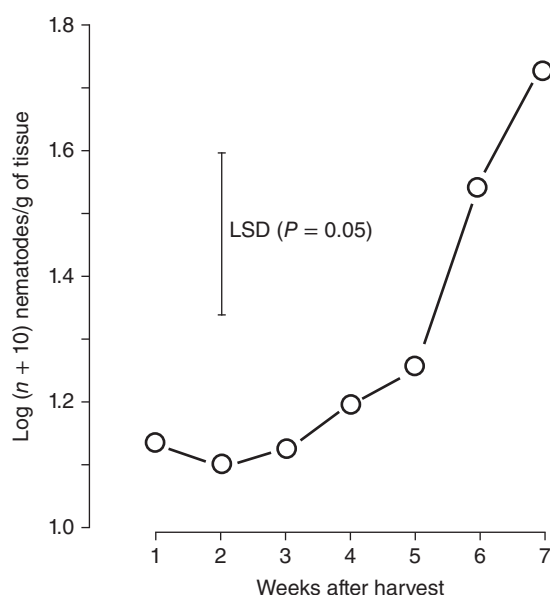


Figure 68 Number of parasitic nematodes extracted from *Dioscorea rotundata* during ambient storage in Jamaica (Thompson et al. 1973b).

while rot development was inhibited at 15 °C. The growth of the fungi increased with increase in relative humidity. The most rapid fungal rot was at 100% r.h., while at 32.5% r.h. the fungal rot was reduced.

Okigbo (2005) investigated the potential of isolates of *Bacillus subtilis* from yam farm soil to control rot of tubers stored in barns. The yams that were inoculated with *Aspergillus niger*, *Botryodiplodia theobromae* or *Penicillium oxalicum* simultaneously with *B. subtilis* and produced rot, whereas those in which *B. subtilis* was inoculated a day before the fungi were inoculated had reduced rot or were completely free of rot.

Infection with parasitic nematodes in the field can cause tissue just below the skin to become necrotic. This necrosis can increase during ambient storage because the nematodes increase in numbers. Storage at 13 °C resulted in a rapid decrease in nematode numbers in the tubers and thus prevented spoilage (Figure 68).

Winged bean

Fabaceae, Leguminosae

Psophocarpus tetragonolobus (L.) DC other common names include aparagus bean, aparagus pea,

four-angled bean, four-cornered bean, Goa bean, Manila bean and Mauntius bean. They are thought to have originated in Africa probably Malagasy or Mauritius (Kay 1979) although Coursey and Booth (1977) and others reported that they were indigenous to Southeast Asia. It is a climbing tropical perennial plant, which produces four sided pods, up to 35 cm long, with characteristic serrated wings running down the four corners (Kay 1979). They contain up to 20 seeds that can be white, yellow, brown or black in colour or even mottled. The edible portion is the immature pods, the fleshy roots, the leaves and the mature seeds. Coursey and Booth (1977) describe their fleshy roots as being edible and higher in protein than is usual for root crops but they commented that it is 'not particularly palatable'. Kay (1987) reported that root tubers contained 52–68% moisture, and on a dry weight basis: 63–77% carbohydrate, 13–20% protein, 0.6–1.4 fat, 1.5–21% fibre and 1.7–3.9% ash, plus 40 mg 100 g⁻¹ calcium, 3 mg 100 g⁻¹ iron and 64 mg 100 g⁻¹ phosphorus. The carbohydrate is about 80% starch and 20% sugars. The chemical content was given by USDA Nutrient Database (2012a) in Table 143.

Harvesting

The pods are harvested while still immature and tender, some 2 weeks after fertilization. If harvesting is delayed they will become fibrous. When grown for seed they are left on the plant until the swollen seeds are clearly visible within the pods. Harvesting is by hand. When grown for tubers, harvesting is normally 4–8 months after sowing. The root tubers are normally harvested when they reach 2.5–5 cm in diameter and 7.5–12 cm in length. Lifting is usually by fork, care being taken to avoid damage; the practice of growing the plants on ridges facilitates this operation. When they are grown on the flat, the ground is sometimes flooded to make digging easier and to reduce the possibility of damage (Kay 1987).

Storage

Seeds with moisture contents of 12.5, 14.5, 16.5 or 18.5% were stored for 24 weeks. All seeds stored at 8 °C retained good colour and odour qualities and high percentage germination. Seeds with a 14.5% moisture content stored above 15 °C and seeds with

Table 143 The composition of winged bean fruit for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

fasd	Fleshy roots	Mature seeds
Water (g)	57.40	8.34
Energy (kcal)	148	409
Protein (g)	11.60	29.65
Total lipid (fat) (g)	0.90	16.32
Carbohydrate, by difference (g)	28.10	41.71
Calcium (mg)	30	440
Iron (mg)	2.00	13.44
Magnesium (mg)	24	179
Phosphorus (mg)	45	451
Potassium (mg)	586	977
Sodium (mg)	35	38
Zinc (mg)	1.39	4.48
Total ascorbic acid (mg)	0	0
Thiamine (mg)	0.379	1.030
Riboflavin (mg)	0.149	0.450
Niacin (mg)	1.640	3.090
Vitamin B-6 (mg)	0.075	0.175
Folate (μg_DFE)	19	45
Vitamin B-12 (μg)	0.00	0.00
Vitamin A (μg_RAE)	0	0
Vitamin A (IU)	0	0
Vitamin D (D2 + D3) (μg)	0.0	0.0
Vitamin D (IU)	0	0
Fatty acids, total saturated (g)	0.222	2.303
Fatty acids, total monounsaturated (g)	0.234	6.012
Fatty acids, total polyunsaturated (g)	0.174	4.330

higher moisture contents stored above 8 °C lost their aesthetic qualities, this loss was associated with the incidence of invasion by storage fungi identified as *Aspergillus glaucus*, *A. flavus* and *A. candidus* (Onsiosan 1986). Germination was reduced by 50% when fresh seed of 20–21% moisture content was stored for 2 weeks and there was no germination after 2 months of storage (Hew and Lee 1981). Refrigerated storage recommendations for pods were as follows:

- 10 °C and 90% r.h. for up to 21 days with up to 21% loss (Tindall 1983);
- 10 °C and 90% r.h. for 28 days (SeaLand 1991).

The root tubers as they are normally eaten immediately after harvest. Kay (1987) reported that in tropical conditions deterioration is rapid through loss of moisture, loss of vitamin C and long cooking time, but at lower temperatures and higher humidities

storage for a few weeks was possible, provided that fungal infections were controlled.

Yacón

Compositae

Polymnia sonchifolia Poepp. and Endl. synonymous with *P. edulis* Wedd. and *Smallanthus sonchifolius* (Poepp. & Endl.) H. Robinson. Other common names include aricama, arboloco jiquima, leafcup, jícama and yacuma. This is an ancient staple perennial herb cultivated in the high Andes from Colombia to north western Argentina at altitudes between 1000 and 3500 m. Research has shown that the largest diversity of its germplasm and therefore its probable centre of origin is on the eastern Andean slopes between 12° and 17° south (Graefe *et al.* 2004). It is found growing wild on the Cundinamarca plateau in Colombia and is typically a peasant crop. Production increased during the widespread drought in the Andean region in 1982–1983. At that time potato production was seriously affected and was replaced in some areas by Yacón with good results (Zardini 1991). This was because Yacón is able to survive in dry agro-ecological areas and is used as a soil protector.

The pleasant-tasting sweet tuberous roots are eaten raw after they have been exposed to the sun for several days until the peel shrivels. The main constituent of the tuberous roots is oligofructans, which are polymers of fructose linked by β-(2 → 1) glucosidic bonds, a carbohydrate in the human body has no enzyme to hydrolyse. Therefore oligofructans are an ideal dietary sugar for diabetics. When eaten they do not increase blood glucose. The juice of the roots can also be concentrated into a syrup to produce a healthy alternative sweetener. In some animal studies there was an indication that fructo-oligosaccharides promote calcium absorption, reduce cholesterol levels, strengthens the immune system and reduces carcinogen lesions in the colon. Additionally, they contain polyphenols with anti-oxidant activity associated with the prevention of cancer and arteriosclerosis (Seminario *et al.* 2003). It is used in diets for invalids in the areas of cultivation in the Andes. Cattle and pigs also eat the roots together with the foliage.

It is a perennial plant with cylindrical stems that grow up to about 2 m in height. The leaves vary in shape, being pinnatifid at the base of the stems and

triangular on the apical part. The flowers appear on terminal branches and have five pointed, green, triangular bracts. The edible portion is the fusiform tuberous root that is up to 20 cm long and 10 cm in diameter. They can weigh as much as 2 kg, although 100–500 g is more usual. They mainly have a soft purplish bark-like skin and transparent orange-coloured watery flesh (Kay 1987).

The tuberous roots contain 10–14% dry matter most of which is carbohydrates and they are traditionally eaten raw or after exposure to the sun for several days that increases their sweetness, which is called sunning or soleado (Graefe *et al.* 2004). The composition of the freshly harvested tuberous roots per 100 g was given by Manrique *et al.* (2004) as moisture 85–90 g, fructo-oligosaccharides 6–12 g, sucrose, fructose and glucose 1.5–4 g, proteins 0.1–0.5 g, potassium 185–295 mg, calcium 6–13 mg and calories 14–22 kcal. The tuberous roots do not contain starch. Graefe *et al.* (2004) reported that exposing freshly harvested tuberous roots on a roof top for 6 days to bright sun resulted in their fructo-oligosaccharides concentrations decreasing from 50–62% to 29–44% and free sugars increasing from 29–34% up to 45–51%. Sunning of the tuberous roots effectively reduced much of their water content; in Graefe's experiment by the reduction was 40%. The average sugar content increased as it becomes concentrated in the roots that were exposed to the sun for 2 weeks. The fructose increased from 2 to 22 g 100 g⁻¹ in fresh roots, α -glucose from 2 to 7 g, β -glucose from 2 to 6 g and sucrose from 2 to 4 g. The sugars are similar to inulin, which is a polysaccharide exclusive to plants found particularly as a storage carbohydrate in members of the Compositae family.

Harvesting

The plants are ready for harvesting in approximately 7 months after planting in the lowlands and in 1 year in the higher areas. They are lifted by hand, usually by levering with a spade from below and pulling the stems. The roots break easily and must be harvested with care and then separated from the central stem, which is used for livestock feed.

Storage

The tuberous root can be stored for several months in a cool dark place (Kay 1987). Graefe *et al.* (2004)

stored roots of different sizes in a dark dry place in a well-aerated bulk of about 40 cm deep for up to 12 days at two altitudes. One at 1990 m that had a temperature range of about 20–28 °C and the other at 2930 m that had a temperature range of about 12–21 °C. After 12 days concentrations of fructo-oligosaccharides were similar at both sites (27–39% of dry matter) and the concentration of fructose, glucose and sucrose increased from 29–34% at harvest up to 48–52%. Graefe *et al.* (2004) found that in storage at ambient temperatures there was a rapid conversion of oligofructose into simple sugars. One week after harvest the oligofructose content of the roots could be reduced by 30–40%. Therefore if products with the highest possible oligofructose content are required, the roots need to be either processed immediately after harvest or stored under refrigeration to minimize oligofructose degradation. Putting the tuberous root out in the sun for a few days to make them sweeter accelerated the conversion process of oligofructose into simple sugars.

Yam

Dioscoreaceae

There are several species of *Dioscorea* that are used for food including

<i>D. alata</i> L.	Water yam
<i>D. altissima</i> Lam.	Dunguey
<i>D. bulbifera</i> L.	Air yam
<i>D. cayenensis</i> Lam.	Yellow guinea yam
<i>D. composita</i> Hemsl.	Yam
<i>D. convolvulacea</i> Cham. & Schltdl.	Yam
<i>D. dumetorum</i> (Kunth) Pax	Bitter yam
<i>D. elephantipes</i> (L'Hér.) Engl.	Hottentot-bread
<i>D. esculenta</i> (Lour.) Burkill	Lesser yam
<i>D. esculenta</i> (Lour.) Burkill var. <i>esculenta</i>	–
<i>D. esculenta</i> (Lour.) Burkill var. <i>tiliaefolia</i> (Kunth) Fosberg & Sachet	–
<i>D. floribunda</i> M. Martens & Galeotti	Yam
<i>D. floridana</i> Bartlett	Florida yam
<i>D. hirticaulis</i> Bartlett	–
<i>D. hispida</i> Dennst.	Intoxicating yam
<i>D. japonica</i> Thunb.	Japanese yam
<i>D. macrostachya</i> Benth.	Yam
<i>D. nummularia</i> Lam.	Yam
<i>D. oppositifolia</i> L.	Chinese yam
<i>D. batatas</i> Decne.	–
<i>D. pentaphylla</i> L.	Fiveleaf yam

<i>D. pilosiuscula</i> Bertero ex Spreng.	Bulbous yam
<i>D. polygonoides</i> Humb. & Bonpl. ex Willd.	Mata gallina
<i>D. praehensilis</i> Benth.	Bush yam
<i>D. preussii</i> Pax	Preuss' dioscorea
<i>D. quaternata</i> J.F. Gmel.	Fourleaf yam
<i>D. glauca</i> Muhl. ex Bartlett	—
<i>D. quaternata</i> J.F. Gmel. var. <i>glauca</i> (Muhl. ex Bartlett) Fernald	—
<i>D. villosa</i> L. var. <i>glabrifolia</i> (Bartlett) Fernald	—
<i>D. rotundata</i> Poir.	Guinea yam
<i>D. sansibarensis</i> Pax	Zanzibar yam
<i>D. spiculiflora</i> Hemsl.	Yam
<i>D. trifida</i> L. f.	Indian yam
<i>D. villosa</i> L.	Wild yam
<i>D. villosa</i> L. var. <i>floridana</i> (Bartlett) H.E. Ahles	—
<i>D. villosa</i> L. var. <i>hirticaulis</i> (Bartlett) H.E. Ahles	—

Source: USDA (2012f)

The name *Dioscorea* is after a Greek physician and naturalist called Dioscoride. The occurrence of *Dioscorea* spp. in southern Asia, Africa and South America and their domestication in these areas appears to have been by aboriginal man. Wild yams and domesticated cultivars occur throughout the tropical and subtropical world as far north as the Pyrenees. West Africa is the most important cultivation area but the crop is also of major importance in parts of eastern Africa, the Pacific area, the Caribbean and South America (Coursey 1967, Kay 1987). *Dioscorea* is of great economic value including important food plants, some wild species are famine foods and others are sources of drugs in both traditional Chinese and western medicine.

Botany

Dioscorea is a large genus of over 600 species with subterranean tubers or rhizomes. There are some 60 species that have been used for food. Many of these are major staple crops in tropical countries with a few in temperate and subtropical countries. The edible portion is the tuber most of which are borne singly, although several small tubers are borne in some species. They have a dark brown skin and usually white flesh, although some have other colours. Also, in some cases, they produce bulbils that also can be eaten. They are perennial but the tops die back and there is a period of dormancy before the plant regrows from the tubers. The length of tuber

dormancy is endogenously controlled and conditions such as availability of soil moisture and temperature can affect when they regrow. There are postharvest implications in dormancy because if tubers are harvested they do not sprout during the early part of storage, even under suitable conditions. The physiological age of tubers also affects when they will sprout and environmental conditions that can affect dormancy including photoperiod, light, temperature, humidity and oxygen partial pressure.

Chemistry

Yam tubers have a high starch content. One class of toxins found in many species is steroidal saponins, which can be converted through a series of chemical reactions into steroid hormones for use in medicine and as a contraceptive. The chemical content was given by USDA Nutrient Database (2012a) in Table 144.

Harvesting

In some species, e.g. *D. rotundata*, *D. cayenensis* and *D. alata*, an early crop may be taken as well as the main harvest; in this case the tuber is carefully cut

Table 144 The composition of yam tubers for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	69.60 g	Thiamine	0.112 mg
Energy	118 kcal	Riboflavin	0.032 mg
Protein	1.53 g	Niacin	0.552 mg
Total lipid (fat)	0.17 g	Vitamin B-6	0.293 mg
Carbohydrate, by difference	27.88 g	Folate	23 µg_DFE
Total dietary fibre	4.1 g	Vitamin B-12	0.00 µg
Sugars, total	0.50 g	Vitamin A	7 µg_RAE
Calcium	17 mg	Vitamin A	138 IU
Iron	0.54 mg	Vitamin E (α-tocopherol)	0.35 mg
Magnesium	21 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	55 mg	Vitamin D	0 IU
Potassium	816 mg	Vitamin K (phyllquinone)	2.3 µg
Sodium	9 mg	Fatty acids, total saturated	0.037 g
Zinc	0.24 mg	Fatty acids, total monounsaturated	0.006 g
Total ascorbic acid	17.1 mg	Fatty acids, total polyunsaturated	0.076 g

below the head and removed, leaving the top to grow again and produce another tuber, or tubers.

Storage

Storage recommendations that did not define which species was being referred to, are as follows were 16 °C and 65% r.h. for 4 months (Mercantilia 1989) and 13.3 °C 85–90% r.h. for 50–115 days (SeaLand 1991).

Pests

The moth pests of yams include *Dasyses rugosella*, *Euzopherodes vapidella* and *Decadarchis minuscula*. *D. alata* was found to be the most susceptible species to infestation (Ashamo 2010).

Viruses

Bousalem *et al.* (2009) reported that virus prevalence data supported the presence of endogenous pararetroviral sequences in *D. rotundata*, but not in *D. abyssinica*, *D. alata*, *D. praehensilis* or *D. trifida*. They found five yam badnavirus species characterized by a wide host range that seemed to be of African origin. Seven other yam badnavirus species with a limited host range were probably of Asian-Pacific origin. They concluded that the risks linked to yam plant introduction and exchanges were high.

Losses

It was reported by Ashamo (2010) that Nigeria accounted for about 70% of world production of yams and in spite of their great economic importance 20–30% were lost during storage. Also in

Nigeria it was reported that storage losses reached 10–15% after the first 3 months and approached 50% after 6 months (Osunde 2008). In Côte d'Ivoire it was reported that yams had postharvest losses estimated at 30% (Doumbia 1990). NAS (1978, quoted by Thompson 2002) estimated total losses of yams to be 10–60%. Coursey (1967) reported weight loss during storage in traditional or improved barns or clamps could reach 10–12% in the first 3 months and 30–60% after 6 months. He also commented that weight losses alone of 33–67% after 6 months of storage had been reported. The magnitude of weight loss in stored yams increased rapidly after the first months (Table 145). In Puerto Rico postharvest losses of yams due to decay exceeded 50% (Burton 1970). Processing losses during culinary preparation of peeled yam could amount to 10–15%. Losses of *D. alata* varied from 7 to 23% during 4 months of storage (Gooding 1960). Afoakwa and Sefa-Dedeh (2001) found that storage of *D. dumetorum* tubers for 110 days in ambient conditions resulted in weight losses of 35% due to sprouting and dehydration. Ezeike (1985) recorded weight losses of *D. alata* over a 5-month period of 60% for those in barn but only 15–25% for those in pits. Yams stored in slatted wooden trays in the coastal region of Cameroon had losses of 29–47% in only 2 months (Lyonga 1985). For *D. trifida* Thompson (1972b) reported fresh weight losses of 29% in Jamaican ambient conditions of about 28 °C for 86 days and for *D. rotundata* weight loss was 16.5% after 34 days.

Minor yam species

D. decaisneana Carr is grown in China where it produces roots that are edible and is synonymous with *D. oppositifolia* L.

Table 145 Percentage weight loss of yams (*Dioscorea* spp.) in conventional local stores (source: adapted from Coursey 1967)

Species	Country of origin	Time in storage in months (%)				
		1	2	3	4	5
<i>D. alata</i>	Trinidad	–	–	–	7–23	–
<i>D. rotundata</i>	Nigeria at Bora	5	7	12	20	29
<i>D. rotundata</i>	Nigeria at Abakaliki	4	6	10	14	21
<i>D. rotundata</i>	Nigeria at Umuahia	3	6	14	23	30
<i>D. cayenensis</i>	Nigeria	6	17	29	39	48
<i>D. rotundata</i>	Ghana	1	5–7	15–17	26–27	34–40

D. deltoidea Wall. ex Griseb. is synonymous with *D. nepalensis* Sweet ex Bern. and *Tamus nepalensis* Jacq. It occurs in the Himalyas up to an altitude of 3500 m (Coursey 1968) and is grown in the East Indies, where it produces edible roots that occur both wild and cultivated in the Indian Archipelago. It is a good source of steroidal sapogenins but due to heavy collection in its native habitat in highlands in India at 1400–3000 m it has become depleted. Experimental cultivation has been attempted in Kenyan highlands and in tropical climates in Bangalore, India, where it shows no dormant period and yield 1.25 kg per plant containing 7–8% diosgenin on a dry weight basis (Purseglove 1972).

D. globosa Roxb. 'East Indies. This species is much cultivated in India as yielding the best kind of yam and is much esteemed both by Europeans and natives. Roxburgh says it is the most esteemed yam in Bengal, but Firminger (1874) thinks it not equal in quality to other varieties. In Burma, Mason says it is the best of the white-rooted kinds' (Sturtevant 1892).

D. hastifolia Nees. Coursey (1967) stated that it is a native of western Australia where the tubers are eaten by Aborigines. 'Australia. The tubers are largely consumed by the aborigines for food, and this is the only plant on which they bestow any kind of cultivation' (Sturtevant 1892).

D. piperifolia Humb. & Bonpl. ex Willd. is synonymous with *D. glandulosa* (Griseb.) Klotzsch ex Kunth and *D. piperifolia* Humb. & Bonpl. ex Willd. var. *glandulosa*. Sturtevant (1892) wrote 'South America. This species has edible roots'. Coursey (1967) reported that it was a Brazilian species that was used as a food by the Amerindians but was little cultivated, but in spite of this it was reported to be cultivated in Argentina, Colombia, Ecuador, Guyana, Peru, Bolivia and Venezuela.

D. pyrenaica Bubani & Bordère ex Gren. It is synonymous with *Borderea pyrenaica*. It is a dwarf species and as the specific name indicates that it is native to the central Pyrenees between Spain and France.

Yam bean

Fabaceae, Leguminosae

Yam bean is a name applied to several plants that produce both edible tubers and seed pods or seeds,

but *Pachyrrhizus erosus* (L.) Urban is probably the most common. It synonymous with *P. angulatus* L. C. Rich. ex DC. Other common names include: jicama, potato bean, frijol de jicama, Mexican yam bean and Mexican water chestnut. It was speculated by NAS (1979) that *P. tuberosus* (Lam.) Spreng., which is also called yam bean, might be a selection of *P. erosus* made because of its larger roots. *P. tuberosus* has entire leaflets, white flowers and longer pods, usually 25–30 cm in length, with irritant hairs and kidney-shaped seeds. It is a native of Mexico and was cultivated by the Toltec, Aztec and Mayan civilisations in pre-Columbian times and was taken by the Spanish to the Philippines. It has subsequently spread to India, the Pacific islands, Indonesia, Malaysia, Vietnam, Laos, Thailand, Cambodia, Myanmar, Taiwan, China and the West Indies (Kay 1987).

A hairy twining herbaceous plant, woody at the base, trailing or climbing to about 6 m with alternate, trifoliate leaves that are toothed or lobed, about as broad as long, usually large, in the range up to 20 cm. The flowers are in long axillary racemes with violet or white petals. The pods are 7.5–15 cm long and about 1.5 cm broad, flattened, almost smooth at maturity, containing 4–12 seeds which are yellow, brown or red, almost square and flattened, 5–10 mm in diameter. Tuberous roots, frequently turnip-shaped, are borne at the base of the stem and may be solitary or several, simple or compound; normally they are about. The edible portion is the white-fleshed tuberous root that are 10–15 cm in diameter and generally turbinate in shape, but this can vary in different growing conditions (Figure 69). Some produce tubers singly but they may be lobed and have subsidiary tubers. It is a refreshing, moist, crisp storage root relatively high in protein. It is consumed raw in salads and low calorie snacks. Immature seed pods can be eaten, but mature seeds are toxic since they may contain the insecticide rotenone (Purseglove 1968).

The tuberous roots contain both starch and sugar and are a moderately good source of ascorbic acid. Average figures for the edible portion have been published as energy 186–264 kJ 100 g⁻¹, water 82.4–87.8%, protein 1.5–2.4%, fat 0.09–1.3%, carbohydrate 10.6–14.9%, fibre 0.6–0.7%, ash 0.5%, calcium 16–18 mg 100 g⁻¹, iron 0.8–1.1 mg 100 g⁻¹, thiamine 0.05–0.1 mg 100 g⁻¹, riboflavin 0.02–0.03 mg 100 g⁻¹, niacin 0.2–0.3 mg 100 g⁻¹



Figure 69 Jicama on sale in a supermarket in California, USA. See colour plate section.

and ascorbic acid 14–21 mg 100 g⁻¹ (Kay 1987). Cantwell (2002a, 2002b) gave the composition of the tuberous roots as about 85% water, less than 1% fibre, less than 1.5% protein, less than 0.5% ash and about 10% carbohydrate, of which about 10% is sucrose. Approximately 65% of the carbohydrate is starch, 20% non-reducing sugars and 15% reducing sugars.

In the Philippines the analysis of the edible portion of the young seed pods was water 86.4%, protein 2.6%, fat 0.3% carbohydrate 10%, fibre 2.9%, ash 0.7%, calcium 121 mg 100 g⁻¹, iron 1.3 mg 100 g⁻¹, phosphorus 39 mg 100 g⁻¹, vitamin A 575 IU/100 g⁻¹, thiamine 0.11 mg 100 g⁻¹, riboflavin 0.09 mg 100 g⁻¹ and niacin 0.8 mg 100 g⁻¹. The analysis of the seeds was water 6.7%, protein 26.2%, fat (oil) 27.3%, carbohydrate 20%, fibre 7% and ash 3.64%. The seeds are toxic and have been studied as a possible commercial source of an insecticide, since they contain 0.12–0.43% of rotenone, pachyrrhizone and pachyrrhizonic acid (Broadbent and Shone 1963, CFNI 1974). The chemical content was given by USDA Nutrient Database (2012a) in Table 146.

Harvesting

Schroeder (1967) indicated that harvest maturity was when the roots had reached 10–15 cm in diameter. Before this the tuberous roots were said to have insufficient flavour and older ones tended to be woody due to lignification.

Table 146 The composition of jicama for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	90.07 g	Thiamine	0.020 mg
Energy	38 kcal	Riboflavin	0.029 mg
Protein	0.72 g	Niacin	0.200 mg
Total lipid (fat)	0.09 g	Vitamin B-6	0.042 mg
Carbohydrate, by difference	8.82 g	Folate	12 µg_DFE
Total dietary fibre	4.9 g	Vitamin B-12	0.00 µg
Sugars, total	1.80 g	Vitamin A	1 µg_RAE
Calcium	12 mg	Vitamin A	21 IU
Iron	0.60 mg	Vitamin E (α-tocopherol)	0.46 mg
Magnesium	12 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	18 mg	Vitamin D	0 IU
Potassium	150 mg	Vitamin K (phylloquinone)	0.3 µg
Sodium	4 mg	Fatty acids, total saturated	0.021 g
Zinc	0.16 mg	Fatty acids, total monounsaturated	0.005 g
Total ascorbic acid	20.2 mg	Fatty acids, total polyunsaturated	0.043 g

Postharvest physiology

Cantwell (2002a, 2002b) gave the respiration rate of the intact tuberous roots as 4–8 at 0 °C, 10–12 at 5 °C, 9.5–19 at 10 °C, 4–8 at 12.5 °C and 5.4–7.2 mg CO₂ kg⁻¹ h⁻¹ at 20 °C. She also recorded that they produce only very low amounts of ethylene at less than 0.1 µl kg⁻¹ h⁻¹, and they are not sensitive to ethylene exposure.

Storage

Delaying harvesting for 2–3 months can be used as a storage method and is achieved by cutting off the tops and not irrigating. Just before harvesting the crop is irrigated to rehydrate the tuberous roots (Schroeder 1967). In Mexico the roots may be harvested, washed and stored in baskets in a cool environment. Moisture loss was reported to be the most important storage problem especially with immature tuberous roots (Schroeder 1967). It was reported by Cantwell *et al.* (1992a) and Mercado-Silva and Cantwell (1998) that roots may develop chilling injury after 1–3 weeks exposure to 10 °C, but no chilling injury was observed on roots stored at 12.5 °C. However Kay (1987) recommended 0 °C for 2 months. Mercado-Silva and

Cantwell (1998) reported that decay was the main external symptom of chilling injury and discolouration and loss of crisp texture were the main internal symptoms. Cantwell (2002a, 2002b) reported that tuberous roots exposed to temperatures had an increased rate of ethylene production of about $0.5 \mu\text{l kg}^{-1} \text{h}^{-1}$. She also noted that their respiration rate was higher at 10°C than at 12.5 or 20°C . Internal discolouration typically occurred from the skin inwards and was more common and more severe in moderately chilled roots stored at 10°C . At lower temperatures, the pulp will take on a translucent appearance but not necessarily develop brown discolouration; these roots probably also exhibit external decay. Kay (1987) reported that storage at 9 – 10°C arrested the tendency of the skin to change colour from creamy white to purplish brown. Storage recommendations were 12.8°C and 65 – 70% r.h. for 30 – 60 days (SeaLand 1991) and 12.5 – 15°C and 80 – 90% r.h. for 2 – 4 months (Cantwell 2002a, 2002b). She also reported that decay development and discolouration of fresh-cut pieces were reduced in storage in 5 – 10% CO_2 .

Diseases

The most common decay organisms found externally on the tuberous roots were species of *Penicillium*, *Rhizopus* and *Cladosporium* usually related to mechanical damage or chilling injury (Bruton 1983, Cantwell *et al.* 1992a).

Yam pie

Dioscoreaceae

Dioscorea trifida L. synonymous with *D. brasiliensis*. Other common names include Cush Cush, Elephant Yam and Indian Yam. It is believed to have originated in South America specifically probably in Guyana. It is now cultivated throughout the northern parts of South America and the Caribbean Islands (to which it was taken by the Arawaks) as far north as the Greater Antilles. It is by far the most important of the indigenous American yams. It has not been successfully introduced into other parts of the tropics where it is grown only on a small scale (Kay 1987). It has received intensive study in Guadeloupe (Rouanet

1967). Sturtevant (1892) wrote 'Guiana and Central America. This species is cultivated as an edible yam'.

Each plant produces up to 50 small tubers at the end of short stolons. These have a brown skin and white flesh and are up to 20 cm long and vary in form from club shaped or spherical. Opara (1999) reported that the content of the edible part of *D. trifida* per 100 g edible tuber portion was water 65–76 g, carbohydrate 38 g, protein 1.9–2.3 g and fibre 0.6 g. Kay (1987) reported the following: protein 2.54%, fats 0.44% and carbohydrate 38% on a fresh weigh basis. The carbohydrate content consisted mainly of starch. The ascorbic acid content was approximately $5.5 \text{ mg } 100 \text{ g}^{-1}$ edible portion, but it was reported to be rapidly lost during storage.

Harvesting and handling

They are normally harvested when the foliage begins to die back, which is some 10 or 11 months after planting. Harvesting is by digging by hand, but mechanical harvesting was being developed with cultivars specially bred for this purpose (Kay 1987). Physical injury during postharvest handling of yams is common in Jamaica. In a study of handling of yampies (Thompson 1972b) it was shown that subjecting the tubers to impacts commonly experienced during handling resulted in greatly increased losses during subsequent storage (Table 147).

Sprouting

The dormancy period of *D. trifida* from the Caribbean was given as 2–4 weeks by Opara (1999) or 4 weeks by Passam (1982). Generally Kay (1987)

Table 147 Effects of dropping *Dioscorea trifida* tubers from various heights onto a concrete floor on storage losses in Jamaican ambient conditions of about 28°C for 86 days (source: adapted from Thompson 1972b)

	Height from which tubers were dropped (cm)				
	0	30	60	90	120
Fresh weight loss (%)	29	43	42	55	64
Fungal score	0	0.1	0.2	0.3	0.4
Necrotic tissue in the flesh (%)	24	55	53	65	84

Fungal score is where 0 = no fungi and 5 = surface covered.

indicated that sprouting in tropical conditions takes between 1 and 8 weeks after harvesting. In Jamaica tubers began to sprout within 3 weeks in storage at 20–29 °C and 46–62% r.h. (Thompson 1972b). Treatment of tubers of two local cultivars in Trinidad immediately after harvest by submergence for 22 h in water that contained 150 µL L⁻¹ gibberellic acid extended the dormancy period to 20 weeks and decreased tuber weight loss to 17% after 13 weeks of storage compared with 26% in the untreated controls (Wickham 1988).

Storage

Loss in weight during storage was rapid at over 1% per day (Kay 1987). Tubers can be stored in cool dry well-ventilated location, possibly for up to a year, but treatment with an insecticide and a fungicide was recommended (Kay 1987). Kay also reported that storage life was normally short under tropical conditions. Tindall (1983) recommended storage in barns at 16–18 °C and 60–65% r.h. Opara (1999) also reported that the optimum conditions for storage of were 25 °C and 60–65% r.h. for several months. Refrigerated storage recommendations were 10 °C for several months (Tindall 1983) and 3 °C for 1 month (Kay 1987, Opara 1999). Conversely, in trials in Jamaica Thompson (1972b) found that tubers stored well at 12 °C with about 84% r.h., but on removal to ambient temperatures they lost weight rapidly, became soft, developed internal necrosis and had copious surface mould growth, which appeared to be due to chilling injury. Controlled atmosphere storage was reported to have only a slight to no effect (SeaLand 1991).

Modified atmosphere packaging

Sealing tubers in polyethylene film bags reduced losses, especially weight loss, but invariably the quantity of fungal mycelium on the tuber surface was increased. In one experiment tubers in polyethylene bags had similar levels of flesh necrosis to those not wrapped (Table 148). However, in another experiment those in polyethylene bags had half the internal necrosis (42%) compared with 82% for those not in polyethylene bags when the tubers had been dropped from the height of 2 m before they were stored. In both cases the tubers would be unmarketable.

Table 148 Effects of packaging material on the quality of *Dioscorea trifida* after 64 days at 20–29 °C and 46–62% r.h (source: adapted from Thompson 1972b)

Packaging type	Weight loss (%)	Fungal score (0–5)	Necrotic tissue (%)
Paper bags	24	0.2	5
Polyethylene bags with 0.15% of the area as holes	16	0.2	7
Sealed 0.03 mm thick polyethylene bags	5	0.4	4

Fungal score was 0 = no surface fungal growth, 5 = tuber surface entirely covered with fungi. Necrotic tissue was estimated by cutting the tuber into two length ways and measuring the area of necrosis and expressing it as a percentage of the total cut surface.

Yellow yam

Dioscoreaceae

Dioscorea cayenensis Lam. but it has also been referred to as *D. oppositifolia* L. In the older literature many taxonomists considered *D. cayenensis* to be a variety of *D. rotundata*. However, Okeke (2004) investigated the taxonomic position of *D. cayenensis*, *D. rotundata* and *D. pruinosa* and found diagnostic characteristics that were more than enough to warrant the recognition of each as separate species. This view was supported by hybridisation experiments, which indicated that members of the group were almost completely inter-sterile. There is considerable variation in both species but even so the differences appear to support Okeke's findings (Table 149). Other common names include 12 months yam, yellow Guinea yam, Guinea yam, Attoto yam, Balugu, Congo amarillo, Cut and come again yam, Dye yam, Hard yam, Igame Guinegame jaune and Niame.

It is a vine that grows up to 10–12 m long with cylindrical or slightly striated stems that are usually spiny, although sometimes completely smooth. The

Table 149 Comparison of characteristics of *Dioscorea cayenensis* and *D. rotundata* (source: adapted from Martin and Sadik 1977)

	<i>D. rotundata</i>	<i>D. cayenensis</i>
Tuber flesh colour	White	Yellow
Leaf shape	Narrowly ovate	Broadly ovate
Climatic preference	Intermediate rainfall	High rainfall
Growing season	7–8 months	10–12 months
Number of harvests	2	1
Possible time of harvest	Limited: late summer	Almost year round

leaves vary from deeply cordate to almost orbicular, 4–20 cm long, opposite or alternate. Some varieties have purplish leaf veins and stems. Male flowers are 1–3 mm in diameter and borne on spikes. The female flowers are much less common and the production of seeds is somewhat rare. The edible portion is the tuber, which is borne singly and can weigh up to 10 kg, but more usually they are within the range of 500 g to 2 kg. They have brown skin and yellow flesh.

Osunde (2008) reported that *D. cayenensis* stored in traditional barns had high losses in moisture, dry matter, crude protein and ascorbic acid after 120 days of storage. However, the stored tubers were rated higher than the fresh tubers by a sensory evaluation panel. Opara (1999) reported that the content of the edible part of *D. cayenensis* 100 g⁻¹ edible tuber portions was water 80 g, protein 1.5 g, carbohydrate 16 g and fibre 0.6 g. In Côte d'Ivoire Kouakou Dje *et al.* (2010) reported that yam tubers of *D. alata* and *D. cayenensis-rotundata* were stored for 6 months in a ventilated store where the conditions were $26.56 \pm 3^\circ\text{C}$ and $82 \pm 5\%$ r.h. The total phenolic content varied in different parts of the tuber and decreased during storage. Protein content ranging from 7.90 to 7.94% and generally did not vary significantly during storage although a slight fall was observed in the distal part of one variety after 6 months. Lipids were low, only about 0.20% of the dry matter, and did not vary significantly during storage. Knoth (1993) gave the following analysis on a fresh weight basis: 58–80% moisture, 15–23% carbohydrates, 0.1–0.2% fats and 1.1–2.0% crude protein.

Harvesting

The vines die back some 12 months after planting and then regrow. At this time the vines can be cut-off and the tubers may be harvested and dug from the ground. Jamaica is a major producer and there they are harvested by digging up the tuber while the vine is still attached. The top of the tuber, called the head end, is cut-off with the vine attached and replanted in the same place. This means that there is a large cut surface on the harvested tuber that is easily infected by micro-organisms.

Curing

Exposure of the tubers to $35\text{--}40^\circ\text{C}$ and 95–100% r.h. for 24 h was found to initiate the curing process and

Table 150 Effects of curing and storage temperature on fresh weight loss (%), fungal score, where 0 = none and 5 = maximum and necrotic tissue in the flesh (%) of *Dioscorea cayenensis* during 127 days of storage (source: adapted from Thompson 1972b)

Storage conditions	Fresh weight loss (%)		Fungal score		Necrotic tissue	
	Not cured	Cured	Not cured	Cured	Not cured	Cured
Ambient	44.8	36.9	0.2	0.0	62	58
13 °C	31.5	26.1	2.9	2.3	96	46

controlled storage rots (Table 150). This treatment could well replace chemical fungicides for postharvest disease control. See the section on *D. rotundata* for details of the process (Thompson *et al.* 1977a). Nnodu (1986) recommended 26°C and 92% r.h. for 11–15 days. Weight loss of *D. cayenensis* was considerable reduced when they were cured (Figure 70) and 78% of the tuber surface was covered with mould after 105 days of storage compared with zero for those that had been cured. Curing also reduced the necrotic tissue (Figure 71) from 55% down to 22% (Thompson 1972b).

Sprouting

At tropical temperatures tubers sprouted some 28 days after harvesting (Coursey 1961). The most popular variety of yellow yam in Jamaica is called Roundleaf and that began to sprout some 90 days after harvest compared with the variety Common that sprouted after some 50 days. This study was at ambient temperatures of $25\text{--}34^\circ\text{C}$ and 64–92% r.h. (Thompson 1972b). Tschannen (2003) reported that GA₃ applied to *D. cayenensis* directly after harvest prolonged dormancy and reduced respiration rate at the time of sprouting. A proprietary potato sprout suppressant containing CIPC and IPC in a dust formulation had no effects on sprouting, but low-temperature storage could delay sprouting. No sprouting occurred on any tubers at 13°C during 5 months of storage, but there was chilling injury at temperatures below 15°C when stored for over a month (Thompson *et al.* 1973a) so this method was not appropriate.

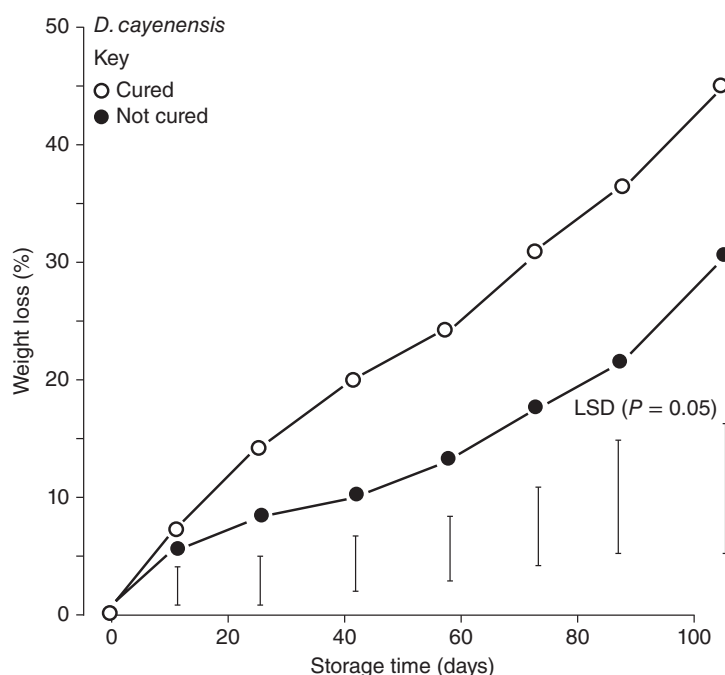


Figure 70 Curing yellow yam tubers (*Dioscorea cayenensis*) on their subsequent weight loss during storage in Jamaican ambient conditions.

Storage

D. cayenensis has a short dormant period and does not store well even under optimum conditions. However, Passam (1982) and Opara (1999) gave a dormancy period of *D. cayenensis* from Nigeria as 4–8 weeks. In ventilated storage in ambient conditions of 24–31 °C and 52–68% r.h. tubers lost 41% in weight after 4 months (Thompson *et al.* 1973a). The storage period was too long and should probably be confined to a maximum of 1 month. Refrigerated storage recommendations were as follows:

- 13 °C and 95% r.h. for less than 4 months with internal necrosis and 29% weight loss (Thompson *et al.* 1973a);
- 16 °C and 80% r.h. for 60 days (Tindall 1983, Opara 1999);
- 13 °C and 95% r.h. for less than 4 months (Opara 1999).

Diseases

A common way of controlling postharvest diseases is to dip the tubers in a fungicide. However, dichloran treatment was found to actually increased rotting

(Thompson *et al.* 1977a). In Jamaica benzimidazole fungicides were used for many years. However, during commercial application, a rot caused by infection with *Penicillium sclerotigenum* was frequently observed on the treated tubers (Plumbly *et al.* 1984, 1985). In *in vitro* tests this organism was found to be tolerant to benomyl. This tolerance was confirmed in *in vivo* tests, but the organism was highly susceptible to the fungicide imazalil that gave good control of the disease (Table 151). This tolerance or resistance commonly occurs with the benzimidazole group of fungicides. However, the use of benomyl or imazalil is now not permitted in many importing countries and an alternative method of disease control is needed. Benomyl use is not permitted in many countries.

Nematodes

Field infestation of yellow yam tubers with parasitic nematode was shown to increase when they were stored in tropical ambient conditions resulting in areas of necrotic tissues. However, when they were stored at 13 °C there was no increase in nematode population in the tubers and no increase

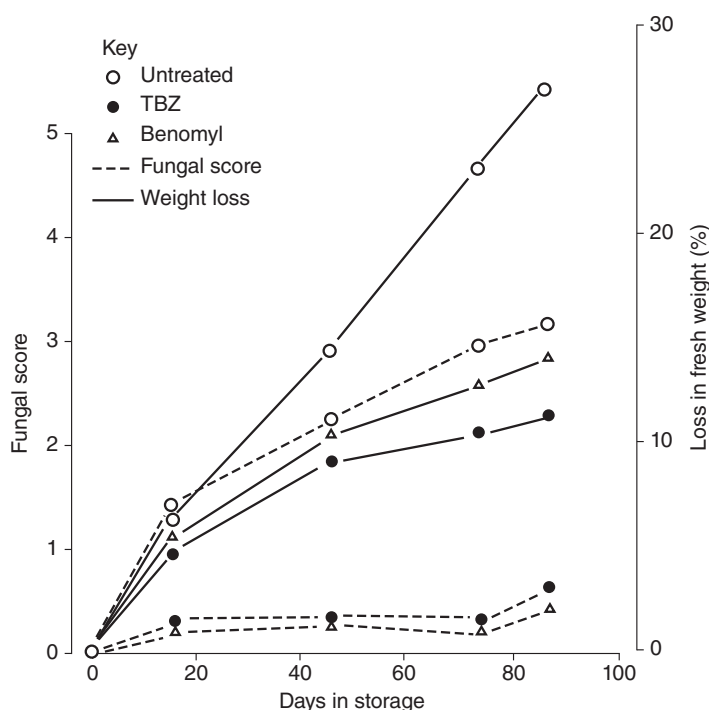


Figure 71 Effects of fungicides of the surface fungi of yellow yam tubers (*Dioscorea cayenensis*) during storage in Jamaican ambient conditions.

Table 151 Effects of benomyl and imazalil on the *in vitro* growth in centimetre of a benomyl tolerant strain of *Penicillium sclerotigenum* on yam tubers (*Dioscorea cayenensis*) during storage at 20 °C (source: adapted from Plumbley *et al.* 1984)

Treatment	Storage time in days				
	0	7	14	21	28
Control	0	1.10	2.20	3.19	3.66
Benomyl 500 µl L ⁻¹	0	0.83	1.87	2.05	3.49
Benomyl 1000 µl L ⁻¹	0	0.60	1.34	2.35	2.99
Imazalil 500 µl L ⁻¹	0	0	0	0	0

in the necrosis associated with nematode damage (Thompson *et al.* 1973b).

Zedoary

Zingiberaceae

Curcuma zedoario (Berg.) Roscoe. Other common names include shoti, Indian arrowroot and kachoor. The origin of zedoary has never been precisely determined, although north eastern India has been

considered by some authorities as the most likely area. It has been cultivated since prehistoric times and has become naturalised throughout the rest of India, South East Asia, southern China, Sri Lanka, Indonesia and the Philippines. It grows wild in the eastern Himalayas and in humid deciduous forests of coastal tracts of Karnataka. It is widely cultivated in many parts of India, Sri Lanka and China (Kundu 1967). Zedoary rhizomes were traded by Arabs from India to Europe by the 6th century CE and achieved their highest popularity in medieval times then declined having been replaced by ginger (*Zingiber officinale*). During the 9th to 13th centuries rhizomes were shipped to Europe for the extraction of a light yellow essential oil. The rhizomes are also used for medicinal purposes and in the manufacture of perfumes and cosmetics in India and an essential oil. The leaves are sometimes used for culinary purposes, especially for cooking fish, and the tender young buds may form an ingredient for salads (Kay 1987). Zedoary starch is valued in India particularly for infant and invalid nutrition and medical properties (Purseglove 1972). The starch, which is similar to that

of arrowroot, is used in India on a cottage industry basis for the preparation of invalid and baby foods. The tuberous rhizomes of wild plants are eaten, after washing, in times of food scarcity. The tubers have been sliced and dried and exported from India in the form of chips for the preparation of starch (Kay 1987). Its flavour is more similar to ginger except with a bitter aftertaste. In Indonesia, it is ground to a powder and added to curries. In India it is mainly used fresh or in pickles and in Thailand it is used raw and cut in thin strips in certain salads or combined with herbs and vegetables with certain types of chilli pastes.

Zedoary is a robust perennial with fleshy, branching rhizomes. Leafy or flowering shoots arise from the ends of the rhizome branches. Main tubers are ovoid with many short thick branches with tuberous

roots. The flesh of the rhizome is yellow (Purseglove 1972). The leafy shoots are up to 1 m tall and consist of a pseudostem of closely compacted concentric leaf bases, with the true stem extending for only part of the way within. It seldom flowers in cultivation, but does so freely when it 'runs wild' (Kay 1987). An analysis of the rhizomes has been given as water 69–70%, starch 12–13% and fibre 18–19%. An analysis of a commercial sample of Indian shoti starch gave water 13.1%, starch 82.6% and ash 1.01%. The starch grains closely resembled those of arrowroot (*Maranta arundinacea*) and had 31.3% amylose content (Kay 1987).

Zedoary normally takes about 10 months to produce a crop. It is usually dug by hand when the leaves begin to wither. The finger rhizomes are carefully separated from the mother rhizomes, which are used for replanting (Kay 1987).

5

Specific recommendations for herbs

The herbs that are included are those used in food preparation although many of them are also used for medicinal purposes.

Bay

Lauraceae

Laurus nobilis L. It is native to the Mediterranean region. It is an evergreen shrub or tree that produces shiny, dark green leaves that are used for flavouring food. The leaves are aromatic and used in cooking. The chemical content was given by USDA Nutrient Database (2012a) in Table 152.

Basil

Labiatae, Lamiaceae

Ocimum basilicum L., lemon basil (*Ocimum* × *citriodourum*). It is native to southern Asia and the Middle East and has long been grown in Europe for its medicinal and culinary properties. The specific name is from the Greek *basilikos* that means royal (Volák and Stodola 1998). It is an annual herb

with opposite stalked ovate slightly toothed glabrous leaves. The chemical content was given by USDA Nutrient Database (2012a) in Table 153.

Hassan and Mahfouz (2010) studied exposure of basil leaves for 8 h of various 1-MCP concentrations (0.2, 0.4 and 0.6 g m⁻³) on their postharvest life and found the optimum to be 0.4 g m⁻³. They reported that 1-MCP significantly retarded the degradation of chlorophyll and protein content of detached leaves, decreased ethylene production and significantly retarded the decrease of volatile oil percentage compared to those not treated during storage in sealed PE bags at 20 °C.

Sirivatanapa (2006) found that in storage in Thai ambient conditions their shelf life was 3–5 days, while CA storage at 0–5 °C with 1–5% O₂ and 5–15% CO₂ extended their shelf life up to 25 days. Wongsheree *et al.* (2009) found that leaves of lemon basil in storage at 4 °C showed browning that was a symptom of chilling injury and was more severe in mature leaves than in young ones. Mature leaves showed higher lipoxygenase activity and lower catalase activity throughout storage at 4 °C compared to young leaves. They concluded that this might indicate more degradation of membrane unsaturated

Table 152 The composition of bay leaves for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	5.44 g	Total ascorbic acid	46.5 mg
Energy	313 kcal	Thiamine	0.009 mg
Protein	7.61 g	Riboflavin	0.421 mg
Total lipid (fat)	8.36 g	Niacin	2.005 mg
Carbohydrate, by difference	74.97 g	Vitamin B-6	1.740 mg
Total dietary fibre	26.3 g	Folate	180 µg_DFE
Calcium	834 mg	Vitamin B-12	0.00 µg
Iron	43.00 mg	Vitamin A	309 µg_RAE
Magnesium	120 mg	Vitamin A	6185 IU
Phosphorus	113 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	529 mg	Vitamin D	0 IU
Sodium	23 mg	Fatty acids, total saturated	2.280 g
Zinc	3.70 mg	Fatty acids, total monounsaturated	1.640 g
		Fatty acids, total polyunsaturated	2.290 g

Table 153 The composition of basil for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.06 g	Thiamine	0.034 mg
Energy	23 kcal	Riboflavin	0.076 mg
Protein	3.15 g	Niacin	0.902 mg
Total lipid (fat)	0.64 g	Vitamin B-6	0.155 mg
Carbohydrate, by difference	2.65 g	Folate	68 µg_DFE
Total dietary fibre	1.6 g	Vitamin B-12	0.00 µg
Sugars, total	0.30 g	Vitamin A	264 µg_RAE
Calcium	177 mg	Vitamin A	5275 IU
Iron	3.17 mg	Vitamin E (α-tocopherol)	0.80 mg
Magnesium	64 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	56 mg	Vitamin D	0 IU
Potassium	295 mg	Vitamin K (phylloquinone)	414.8 µg
Sodium	4 mg	Fatty acids, total saturated	0.041 g
Zinc	0.81 mg	Fatty acids, total monounsaturated	0.088 g
Total ascorbic acid	18.0 mg	Fatty acids, total polyunsaturated	0.389 g

fatty acids and suggested lower protection against membrane oxidation in mature leaves. Lange and Cameron (1998) reported that MA packaging increased the shelf life of leaves.

Borage

Boraginaceae

Borago officinalis L. It is native to the Mediterranean region from where it has spread throughout Europe (Volák and Stodola 1998). It is an annual herb with a tap root and alternate pointed ovate, sessile leaves. It is grown for its leaves, flowers and seeds. The chemical content was given by USDA Nutrient Database (2012a) in Table 154. *B. officinalis* seed contains a high content of γ-linolenic acid, which is a precursor of the prostaglandin in the human body. Prostaglandin is vital in many body functions, including antithrombotic inhibitory effects, lowering blood pressure and inhibiting cholesterol formation (Coupland 2008). Berti *et al.* (2010) carried out fertilizer trials on *B. officinalis* and found that N rates increased γ-linolenic acid content. Alcúson *et al.* (n.d.) reported that borage leaves are cut and packaged in expanded polystyrene trays covered with stretch PVC films. In this minimally processed form they are popular in the Ebro valley of Spain. They compared storage at 4 °C in active MA packaging (with an initial gas composition of 5% O₂, 5% CO₂ and 90% N₂), passive MA packaging or vacuum packaging. The samples in active and passive MA packaging maintained their colour and texture, but total mesophilic aerobic microorganism counts were higher than five

Table 154 The composition of borage leaves for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	93.00 g	Thiamine	0.060 mg
Energy	21 kcal	Riboflavin	0.150 mg
Protein	1.80 g	Niacin	0.900 mg
Total lipid (fat)	0.70 g	Vitamin B-6	0.084 mg
Carbohydrate, by difference	3.06 g	Folate	13 µg_DFE
Calcium	93 mg	Vitamin B-12	0.00 µg
Iron	3.30 mg	Vitamin A	210 µg_RAE
Magnesium	52 mg	Vitamin A	4200 IU
Phosphorus	53 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	470 mg	Vitamin D	0 IU
Sodium	80 mg	Fatty acids, total saturated	0.170 g
Zinc	0.20 mg	Fatty acids, total monounsaturated	0.211 g
Total ascorbic acid	35.0 mg	Fatty acids, total polyunsaturated	0.109 g

logarithmic units after 9 days for passive MA packaging as well as after 12 days for active MA packaging, although the CO₂ was some 10%.

Chervil

Apiaceae

Anthriscus cerefolium L. (Hoffm.). They are a native of southern Europe and the Levant. It is an annual herb that is grown for its leaves whose flavour resembles parsley and fennel, but is more aromatic. They are used in salads and flavouring soup.

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and MA packaging was shown to increase their shelf life. They also studied freshly harvested chervil under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in sealed polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay. However sealed film packaging was applicable only if the temperature during transit did not fluctuate. This is probably because condensation was controlled; otherwise perforated polyethylene liners were better. In other experiments chlorophyll degradation was delayed effectively when 5% CO₂ in air was applied in a flow-through system (Aharoni *et al.* 1993).

Chives

Alliaceae, Liliaceae

Allium schoenoprasum L. USDA (2012b) gives wild chives as *A. schoenoprasum* L., *A. schoenoprasum* L. var. *schoenoprasum*, *A. schoenoprasum* L. var. *sibiricum* (L.) Hartm., *A. schoenoprasum* L. var. *laurentianum* Fernald and *A. schoenoprasum* L. subspecies *sibiricum* (L.) Celak. Purselove (1972) reported that wild plants are widely distributed throughout the world in many and varied environments they will withstand frosts and drought. Chives have been used in Europe since the 16th century, although its date of original domestication is not known. It is a perennial herb up to about 30 cm tall with small densely packed bulbs and purple flowers. The edible part is the leaves that have a mild onion flavour and are used to garnish and flavour foods. As they grow the plants

tiller and form dense clumps of bulbs. The leaves are cut close to the ground and brown leaves and flower stalks are discarded before bunching. Most herbs for fresh culinary use are best if harvested before flowering but chive blossoms are sometimes used in salads or as edible garnishes.

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and their respiration rate was reported to be, in milligrams of carbon dioxide per kilogram-hour, 22 at 0 °C, 110 at 10 °C and 540 at 20 °C (Wright 2002). There is little information on its storage life but 0–1 °C and 95–100% r.h. for 1–2 weeks was recommended by Snowdon (1991), and Wright (2002) recommended 0 °C and 95–100% r.h. for 2–3 weeks. No direct information was found on controlled atmosphere storage but chlorophyll degradation was delayed effectively when they were stored in 5% CO₂ in air applied in a flow-through system (Aharoni *et al.* 1989).

In an experiment green tops of chives were bunched, 25–30 g per bunch, packed in perforated or non-perforated polythene bags (20 × 25 cm) and stored at 2, 5, 10, 15 or 20 °C by Umiecka (1973). The control was kept unpacked. The tops stored better in non-perforated than in perforated bags and the longest satisfactory storage of 14–21 days was in non-perforated bags at 2 °C. The non-packed control kept well for 1–2 days at 2 °C but deteriorated rapidly at the higher temperatures. Aharoni *et al.* (1989) studied freshly harvested chives under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in sealed polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay. However sealed film packaging was applicable only if the temperature during transit and storage was well-controlled; otherwise perforated polyethylene was better.

Chinese chives

Alliaceae, Liliaceae

Allium tuberosum Rottl. ex Sprengel. Other common names include Chinese onion, garlic chives, kow choi and green nira grass. They probably originated in China, but they have spread throughout the world. They are perennial herbs that grow in

dense clumps up to 40 cm high with white flowers. They have a prominent rhizome but bulbs are scarcely formed (Purseglove 1972). The edible portions are the young thin flattish leaves and inflorescences. It grows in slowly expanding perennial clumps. They have a strong pleasantly sweet garlic flavour and are used for seasoning. Jorge *et al.* (2001) found that sulphur compounds accounted for 88% of the total volatiles in the isolated extract of Chinese chives. There were 27 novel, volatile sulphur-containing components in the isolated extracts; among them were a sulphide, disulphides, trisulphides and tetrasulphides with ethyl, butyl and pentyl groups.

The young leaves have the strongest flavour and regular harvest will ensure a constant supply of new leaves. Snowdon (1991) mentioned that they have a high respiration rate and therefore it is desirable to pre-cool them possibly with top icing. Wu *et al.* (2009) treated Chinese chives with $0.5 \mu\text{L}^{-1}$ 1-MCP, which significantly reduced respiration rate, weight loss, opening rate of flowers and the activities of phenylalanine ammonia lyase, cinnamyl alcohol dehydrogenase and peroxidase. Higher chlorophyll and ascorbic acid contents were also maintained. 1-MCP retarded lignin and cellulose accumulation.

Their respiration rate was reported to be, in milligrams of carbon dioxide per kilogram-hour, 54 at 10°C , 99 at 15°C and 432 at 20°C (Wright 2002). The optimum storage temperature was approximately 3°C and at that temperature they could be stored for 26 days (Wu 1998). Wright (2002) recommended 0°C with 95–100% r.h. for 1–2 weeks. Ishii and Okubo (1984) recommended that bundles of about 110 g should be sealed in polyethylene bags with 10 bundles per bag and a bag size of about 30×45 cm and about 0.025 mm in thickness. Four bags should be vertically packed in a corrugated box and cooled to 5°C within a day. The cooled produce may be transported in insulated containers. Film wrapping was said to be effective in maintaining their freshness and at 3°C losses through decay and flower opening were reduced to less than 1% after 26 days when polypropylene film wrapping was used (Wu 1998).

Coriander

Umbelliferae

Coriandrum sativum L. also called cilantro and Chinese parsley. It is native from the eastern Mediterranean

Table 155 The composition of coriander for 100 g^{-1} fresh weight (source: adapted from USDA 2012a)

Water	92.21 g	Thiamine	0.067 mg
Energy	23 kcal	Riboflavin	0.162 mg
Protein	2.13 g	Niacin	1.114 mg
Total lipid (fat)	0.52 g	Vitamin B-6	0.149 mg
Carbohydrate, by difference	3.67 g	Folate	62 μg _DFE
Total dietary fibre	2.8 g	Vitamin B-12	0.00 μg
Sugars, total	0.87 g	Vitamin A	337 μg _RAE
Calcium	67 mg	Vitamin A	6748 IU
Iron	1.77 mg	Vitamin E	2.50 mg
		(α -tocopherol)	
Magnesium	26 mg	Vitamin D	0.0 μg
		(D2 + D3)	
Phosphorus	48 mg	Vitamin D	0 IU
Potassium	521 mg	Vitamin K	310.0 μg
		(phyloquinone)	
Sodium	46 mg	Fatty acids, total saturated	0.014 g
Zinc	0.50 mg	Fatty acids, total monounsaturated	0.275 g
Total ascorbic acid	27.0 mg	Fatty acids, total polyunsaturated	0.040 g

region to India and has been cultivated for at least 3000 years. The name *Coriandrum* is said to be derived from the Greek *koris* meaning bug (Volák and Stodola 1998). It is an annual herb and the edible part is the leaves, but they are commonly marketed with their tap root still attached. They are cooked as a vegetable and the young leaves are used for pickles and sauces. The dried fruits are used as a spice, especially to flavour curries and gin. The chemical content was given by USDA Nutrient Database (2012a) in Table 155.

Storage

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and their storage life was found to be 1 day at room temperature of $17\text{--}30^\circ\text{C}$ with 24–73% r.h. (Waskar *et al.* 1998). Yellowing was accelerated during storage in $0.4 \mu\text{L}^{-1}$ ethylene compared to storage in air (Lee *et al.* 2000). Refrigerated storage recommendations include:

- 0°C and 90–95% r.h. for 1 week (Amezquita Garcia 1973).
- $0\text{--}1.7^\circ\text{C}$ and 90% r.h. for 5 weeks (Pantastico 1975).

- 6–7 days at 8 °C and 90–92% r.h. (Waskar *et al.* 1998).
- 4 °C for 1 week, although weight loss was approximately 50% (Gomez *et al.* 1999).

Modified atmosphere packaging

Modified atmosphere packaging was reported to lengthen the shelf life of coriander (Loiza and Cantwell 1997). Storage in 50 µm PE bags with 2% ventilation was recommended by Waskar *et al.* (1998). 0 °C in modified atmosphere packaging with thicker film gave a longer storage life without detrimental effects (Lee *et al.* 2000). Aharoni *et al.* (1989) recommended packaging in perforated polyethylene-lined cartons.

Transport

Aharoni *et al.* (1989) studied freshly harvested coriander under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in perforated polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay. In other experiments, chlorophyll degradation was delayed effectively when 5% CO₂ in air was applied in a flow-through system.

Dill

Umbelliferae, Apiaceae

Anethum graveolens L. It is native to the eastern Mediterranean and western Asia. The name dill is thought to come from the old Norse word *dylla* probably meaning to soothe (Volák and Stodola 1998). It is an annual herb that produces a small brown fruit called a double achene, which is elliptical and prominently ribbed and about 3 mm long. The stems, leaves and particularly the seeds are used as food flavouring. It also has medicinal properties. The chemical content was given by USDA Nutrient Database (2012a) in Table 156.

Storage

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and Umiecka (1973) reported that the

Table 156 The composition of dill for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	85.95 g	Total ascorbic acid	85.0 mg
Energy	43 kcal	Thiamine	0.058 mg
Protein	3.46 g	Riboflavin	0.296 mg
Total lipid (fat)	1.12 g	Niacin	1.570 mg
Carbohydrate, by difference	7.02 g	Vitamin B-6	0.185 mg
Total dietary fibre	2.1 g	Folate	150 µg_DFE
Calcium	208 mg	Vitamin B-12	0.00 µg
Iron	6.59 mg	Vitamin A	386 µg_RAE
Magnesium	55 mg	Vitamin A	7718 IU
Phosphorus	66 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	738 mg	Vitamin D	0 IU
Sodium	61 mg	Fatty acids, total saturated	0.060 g
Zinc	0.91 mg	Fatty acids, total monounsaturated	0.802 g
		Fatty acids, total polyunsaturated	0.095 g

leaves kept well for 1–2 days at 2 °C. Quantitative and qualitative changes were investigated in dill harvested at three stages of maturity and stored for 1–15 days. The essential oil content rose during the first 48 h of storage and then gradually declined to 21.2% of that in the fresh material on the fifteenth day. Phellandrene increased and carvone decreased during storage (Zlatev *et al.* 1976). No direct information could be found on CA storage, but Aharoni *et al.* (1989) found that chlorophyll degradation was delayed effectively in 5% CO₂ in air.

Modified atmosphere packaging

Green tops were bunched (25–30 g per bunch), packed in perforated or non-perforated polythene bags (20 × 25 cm) and stored at 2, 5, 10, 15 or 20 °C. The control was kept unpacked. The tops stored better in non-perforated than in perforated bags and the longest satisfactory storage (9–12 days) was obtained in non-perforated bags at 2 °C. The non-packed control kept well for 1–2 days at 2 °C but deteriorated rapidly with rising temperature (Umiecka 1973, 1989).

Transport

Aharoni *et al.* (1989) studied freshly harvested dill under simulated conditions of air transport from

Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in perforated polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay.

Fennel

Umbelliferae, Apiaceae

Foeniculum vulgare. It is a native of the Caucasus and the Mediterranean region and has become naturalized throughout Europe. The name *Foeniculum* is thought to have been derived from the Latin *foenium* meaning hay. Fennel was used by the Romans in ancient times (Volák and Stodola 1998). It is a biennial and the young leaves are used as flavouring and the seeds, which contain the essential oils anethole and fenchone, are used medicinally. The taproot is also edible. The swollen leaf bases are used as a vegetable, eaten raw in salads or boiled and have a distinctive anis flavour (Figure 72). The swollen leaf bases are harvested when they have reached an acceptable size, but are still tender. If they are left too long they become tough and stringy.

At room temperature of 20 °C and 60% r.h. the swollen leaf bases could be kept for 2–3 days (Mercantilia 1989). Refrigerated storage recommendations for the swollen leaf bases were 0 °C and 90–95% r.h. for 14–28 days (Mercantilia 1989, SeaLand 1991) and 0–1 °C and 95% r.h. for 1–2 weeks (Snowdon 1991).

Hyssop

Labiatae, Lamiaceae

Hyssopus officinalis L. synonymous with *H. decumbens* Jord. and Fourr. Pérez Maté (2002) reported that it was a native to southern Europe and the Middle East, and the region surrounding the Caspian Sea. It can be found in Asia and around the Mediterranean. Hyssop is a name of Greek origin. The Hyssopsus of the time of Discorides was named from azob, a holy herb. The word hyssop was mentioned in the Bible 12 times (10 times in the Old Testament and twice in the New Testament), for example 'the cedar tree that is in Lebanon even unto the hyssop that springeth out of the wall:' 1 Kings 4:33. It was also used for



Figure 72 Fennel on sale in a UK shop in January 2013.

ritual cleansing 'and a clean person shall take hyssop, and dip it in the water and sprinkle it upon the tent' Numbers 19:18. The Romans are thought to have introduced it into the United Kingdom. It is a herb that has been used from ancient times for salads and flavouring stews and meat. Due to its medicinal properties it is commonly used in homeopathy usually as an expectorant. Its flavour is described as slightly bitter and minty and is used in the liqueur Chartreuse. For centuries it was used as a medicinal herb against coughs and catarrh and it was part of an old English country remedy for cuts and wounds suffered working in the fields where a poultice of bruised hyssop leaves and sugar was used in order to reduce the risk of tetanus infection. Another perennial herb from the same family is anise hyssop (*Agastache foeniculum*).

Hyssop is an evergreen, shrubby, brightly coloured perennial. It grows to about 60 cm high, with long, thin, sharp-pointed leaves. It has long, narrow spikes which flower from June to October and there are several varieties with blue, purple, pink or white flowers and the fruit is an achene. It has a woody stem with straight branches. The main chemical components of hyssop oil are α -pinene, camphene, β -pinene, sabinene, myrcene, limonene, pinocamphone, isopinocamphone, γ -terpineol, 1,8-cineole and thujone.

It is usually harvested just before it begins to flower or just after it has started to flower. Sometimes a second cut is taken. However the young leaves can be

harvested throughout its growing period and they can be preserved by drying. For medicinal purposes they should be harvested on a dry day at the peak of their maturity and the concentration of active ingredients is highest and can be dried quickly, away from bright sunlight in order to preserve their aromatic ingredients and prevent oxidation of other chemicals. The dried leaves can be stored in airtight containers for up to 18 months.

Respiration rate increased from 484 W tonne⁻¹ at 10 °C to 1080 W tonne⁻¹ at 20 °C and 2041 W tonne⁻¹ at 30 °C (Bottcher and Gunther 2001). Plants at approximately the 50% flowering stage were harvested and stored at 10 °C with 98% r.h., 20 °C with 95% r.h. or 30 °C with 92–97% r.h. by Bottcher and Gunther (2001). The loss of dry matter was 1.6% at 10 °C, 3.0% at 20 °C and 6.5% at 30 °C over a 24-h period after harvest. The colour and external quality of the harvested herbs was best maintained at 10 °C.

Lemon balm

Labiatae, Lamiaceae

Melissa officinalis. Its origin is the Mediterranean region and its generic name means honeybee in Greece where it is much prized for its fragrant flavour (Volák and Stodola 1998). The leaves are used for infusion to make tea as well as to flavour food and for extraction of essential oils. It is perennial grown as a herb.

It is normally harvested two or three times a year by cutting the plant close to the ground. The contents and composition of essential ingredients changed with cutting date and length of postharvest storage. In the more favourable second cut, the content of essential oils was twice as high as the first cut and contained higher quantities of citral A and B, geraniol, citronellal and geranylacetate, but less linalool and β -caryophyllene (Bottcher *et al.* 2000).

Bottcher *et al.* (2000) found the harvested leaves have a high respiration rate at 10 °C of 523 ± 109 W tonne⁻¹, at 20 °C of 1190 ± 202 W tonne⁻¹ and at 30 °C of 2342 ± 232 W tonne⁻¹. In this study the comparatively high respiration rates continued throughout a postharvest period of 80 h. As would be expected postharvest quality was better after storage at 10 °C than at 20 or 30 °C.

Lemongrass

Poaceae

Cymbopogon spp. *C. flexuosus* is called East Indian lemongrass, *Cochin* and *Malabar grass* and is native to India and Sri Lanka. *C. citratus* is called West Indian lemongrass and is native to southern India, Sri Lanka, Indonesia and Malaysia (Anonymous 2012). *C. flexuosus* is a fast-growing, lemon-scented, perennial grass reaching a height of 1.5 m. It has distinct, dark green foliage and also produces seed. *C. citratus* is also a fast-growing, lemon-scented, perennial grass reaching a height of 1 m. It has distinct bluish green leaves and usually does not produce seed. Both these grasses produce many bulbous stems that increase the clump diameter as the plants mature (Anonymous 2012). Lemongrass contains citral which is a natural combination of two isomeric aldehydes, namely isomers geranial (α -citral) and neral (β -citral) as well as limonene, citronellal, β -myrcene and geraniol (Schaneberg and Khan 2002, Pengelly 2004).

Harvesting and handling

The first harvest can take place from some 6–9 months after planting. The grass can then be harvested frequently during the active growing season, up to once every month. Frequent cutting stimulates growth. The oil yield will be reduced if the plant is allowed to grow too large. The grass should be harvested early in the morning, provided it is not raining, allowing heavy dew to evaporate in order to avoid colour loss during a hot day. The plants are harvested mechanically or by hand. The grass is cut to 10–15 cm above ground level; if it is cut too low regrowth will be delayed. Also the oil content is optimal in the upper parts of the plant. Should the grass be cut too low, there will be less oil in the leaves. Up to three harvests can be obtained in the first year and up to 5–10 harvests during each of the 3–5 succeeding years, depending on soil moisture status, management and weather (Anonymous 2012). In Malaysia Tajidin *et al.* (2012) found that citral content peaked at 6.7 ± 0.3 months after planting, and harvesting 5.5 and 6.5 months after planting had significantly higher oil content than those harvested at 7.5 months. The citral content at 6.5 months after planting was higher by 11.4% than at 5.5 months after planting and decreased by 5.4% when lemongrass

was harvested at 6.5 compared to at 7.5 months after planting.

Storage

Lemongrass oil should be stored in dark, air-tight, glass bottles not exposed to heat or heavy metals. Once opened, refrigeration and tightly closing the cap will prolong its shelf life. Deterioration begins if the liquid is much darker or more viscous than normal. Lemongrass oil is very acidic and will destroy plastic and rubber in a short time (Anonymous 2012).

Modified atmosphere packaging

Lemongrass leaves were hot-water-treated at 55 °C for 5 min, then hydrocooled at 3 °C for 5 min and placed in PE bags, which were then flushed with various levels of O₂ + CO₂. They were then sealed and stored at 5 °C and 90 ± 5% r.h. for 3 weeks. They found that *E. coli* was inhibited in 1% O₂ + 10% CO₂, and coliforms and fecal coliforms were inhibited in 5% O₂ and *Salmonella* at all gas mixtures for up to 14 days. Fungal infections were not controlled in any of the atmospheres tested (Samosornsuk *et al.* 2009).

Marjoram, oregano

Labiatae, Lamiaceae

Marjoram (*Origanum majorana*, synonymous with *Majorana hortensis* Moench, *M. majorana* (L.) H. Karst. *O. hortensis* L. and *O. vulgare*) is also called wild marjoram and oregano. Sweet marjoram, also called knotted marjoram, *O. majorana* (L.) H. Karst. is synonymous with *M. hortensis* Moench. In some Middle Eastern countries marjoram is synonymous with oregano, and there the names sweet marjoram and knotted marjoram are used to distinguish between the two.

It is native to the Mediterranean region and was cultivated by the ancient Egyptians, Greeks and Romans and was probably introduced to Britain in the Middle Ages. Depending on the species it is an annual or biennial herb or subshrub or it is a somewhat cold sensitive perennial herb or undershrub with sweet pine and citrus flavours. The flowering stems contain 1–2% of a fragrant essential oil that contains terpinenes and terpinols as well as tannins,

carotenes and ascorbic acid (Volák and Stodola 1998). Most herbs for fresh culinary use are best if harvested before flowering but marjoram is sometimes sold with flower buds (Cantwell 1997, Wright 2002).

Respiration rate of marjoram was reported to be 28 mg CO₂ kg⁻¹ h⁻¹ at 0 °C and 68 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and for oregano as 22 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 101 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 176 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Wright 2002). They can be stored at 0 °C and 90–95% r.h. for 1–2 weeks (Cantwell 1997, Wright 2002).

Matricaria

Compositae, Asteraceae

Matricaria recutita synonymous with *M. chamomilla* L. and *Chamomilla recutita*, which is also called chamomile.

It is an annual herb with a branched erect stem with solitary terminal flower heads. The flowers have white ray florets and yellow disc florets. The flowers are used medicinally and contain up to 1% of the essential oil azulene as well as bisabolol, farnescene, flavonoid and coumarin glycosides (Bottcher *et al.* 2001).

In Germany they are mechanically harvested from autumn and spring sown crops. The flowers need ventilating, cooling or drying directly after harvest (Bottcher *et al.* 2001).

During storage of the cultivar Bodegold for 80 h, Bottcher *et al.* (2001) showed that the harvested flowers had a high respiration rate of 999 ± 134 W tonne⁻¹ at 10 °C, 2438 ± 289 W tonne⁻¹ at 20 °C and 4552 ± 570 W tonne⁻¹ at 30 °C. In a comparison of three temperatures, 10, 20 and 30 °C, Bottcher *et al.* (2001) found that losses were lowest at 10 °C. Constituents of the flowers decreased only slightly during 80 h storage. The valuable α -bisabolol and its A and B oxidised forms showed the greatest loss at 10 °C, but responded differently in different trials with losses between 10 and 80%.

Mint

Labiatae, Lamiaceae

Mentha L. spp. There are many different species and therefore flavours of mint including:

- *M. aquatica* var. *crispa* is water mint or curly mint,

- *M. citrata* is eau de Cologne mint,
- *M. piperita* L., *M. x piperita* is the peppermint,
- *M. pulegium* is pennyroyal,
- *M. rotundifolia* is apple mint or bowles mint,
- *M. rotundifolia variegata* is pineapple mint,
- *M. spicata* L. is spearmint.

They are all perennial herbs that spread rapidly by underground stolons. The leaves have been used from ancient times for flavouring and they also have medicinal and digestive properties. The chemical content was given by USDA Nutrient Database (2012a) in Table 157. Respiration rate was reported to be, in milligrams of carbon dioxide per kilogram-hour, 20 at 0 °C, 76 at 10 °C and 252 at 20 °C (Wright 2002).

For storage Snowdon (1991) recommended 0–1 °C and 95–100% r.h. for 2–4 weeks and Wright (2002) similarly recommended 0 °C with 95–100% r.h. for

Table 157 The composition of *Mentha* leaves for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

	Peppermint	Spearmint
Water (g)	78.65	85.55
Energy (kcal)	70	44
Protein (g)	3.75	3.29
Total lipid (fat) (g)	0.94	0.73
Carbohydrate, by difference (g)	14.89	8.41
Total dietary fibre (g)	8.0	6.8
Calcium (mg)	243	199
Iron (mg)	5.08	11.87
Magnesium (mg)	80	63
Phosphorus (mg)	73	60
Potassium (mg)	569	458
Sodium (mg)	31	30
Zinc (mg)	1.11	1.09
Total ascorbic acid (mg)	31.8	13.3
Thiamine (mg)	0.082	0.078
Riboflavin (mg)	0.266	0.175
Niacin (mg)	1.706	0.948
Vitamin B-6 (mg)	0.129	0.158
Folate (µg_DFE)	114	105
Vitamin B-12 (µg)	0.00	0.00
Vitamin A (µg_RAE)	212	203
Vitamin A (IU)	4248	4054
Vitamin D (D2 + D3) (µg)	0.0	0.0
Vitamin D (IU)	0	0
Fatty acids, total saturated (g)	0.246	0.191
Fatty acids, total monounsaturated (g)	0.033	0.025
Fatty acids, total polyunsaturated (g)	0.508	0.394

2–3 weeks. Mint can be infected with rust caused by *Puccinia menthae* Pers., which causes small brown pustules to form on leaves (Snowdon 1991).

Parsley

Apiaceae

Petroselinum crispum (Mill.) Nyman ex A.W. Hill, synonymous with *P. sativum* and *P. sativa*. Hamburg parsley *P. crispum* subspecies *tuberosum* produces an edible root. The edible portion is the leaves and young stems but the taproot can also be eaten. The freezing point was given as –1.28 to –1.11 °C (Weichmann 1987). The chemical content was given by USDA Nutrient Database (2012a) in Table 158.

Harvesting

Flower shoots should be removed in the field as they appear because they will shorten the productive life of the crop. Parsley leaves can be harvested progressively or cut all at one time.

Table 158 The composition of the leaves and young stems of parsley for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	87.71 g	Thiamine	0.086 mg
Energy	36 kcal	Riboflavin	0.098 mg
Protein	2.97 g	Niacin	1.313 mg
Total lipid (fat)	0.79 g	Vitamin B-6	0.090 mg
Carbohydrate, by difference	6.33 g	Folate	152 µg_DFE
Total dietary fibre	3.3 g	Vitamin B-12	0.00 µg
Sugars, total	0.85 g	Vitamin A	421 µg_RAE
Calcium	138 mg	Vitamin A	8424 IU
Iron	6.20 mg	Vitamin E (α-tocopherol)	0.75 mg
Magnesium	50 mg	Vitamin D (D2 + D3)	0.0 µg
Phosphorus	58 mg	Vitamin D	0 IU
Potassium	554 mg	Vitamin K (phylloquinone)	1640.0 µg
Sodium	56 mg	Fatty acids, total saturated	0.132 g
Zinc	1.07 mg	Fatty acids, total monounsaturated	0.295 g
Total ascorbic acid	133.0 mg	Fatty acids, total polyunsaturated	0.124 g

Chemical treatments

Ella *et al.* (2003) reported that a single application of 1-MCP at $10 \mu\text{L L}^{-1}$ could be used to retard senescence of parsley leaves early in their storage life, but they also found that this treatment could increase ethylene biosynthesis. A preharvest spray with gibberellic acid may reduce yellowing and extend their storage life (Lers *et al.* 1998).

Pre-cooling

Vacuum pre-cooling was recommended by Aharoni *et al.* (1989) and package icing or liquid icing (Cantwell and Reid 1993) and forced air or hydro-cooling are commonly practised (Joyce *et al.* 1986). Rapid removal of field heat without excessive drying is advantageous for retaining green colour and freshness of parsley.

Postharvest physiology

Parsley leaves produced very little ethylene but were very sensitive to exogenous exposure to ethylene (Joyce *et al.* 1986). Cantwell and Reid (1993) observed that parsley leaves produced ethylene, in microlitre per kilogram-hour: 0.08 at 0°C , 0.44 at 10°C and 0.80 at 20°C . As little as $0.4 \mu\text{L L}^{-1}$ accelerated yellowing at temperatures above 0°C (Cantwell and Reid 1993), but they showed no response in their respiration rate to exposure to $100 \mu\text{L L}^{-1}$ of ethylene for 24 h at any temperature over the range of $5\text{--}35^\circ\text{C}$ (Inaba *et al.* 1989). The leaves have a high respiration rate, which is higher in the younger leaves at harvest compared to the older ones. Younger leaves store better since the respiration rate decreases more during storage in younger leaves than in the older ones (Apeland 1971). Data on respiration rates are presented in Table 159.

Table 159 Respiration rate of parsley at different temperatures measured 3 days after harvest (source: adapted from Heyes 2002)

Temperature ($^\circ\text{C}$)	mg CO_2 $\text{kg}^{-1} \text{h}^{-1}$
0	22–38
5	49–70
10	78–150
15	131–168
20	176–221
25	259–289

Storage

Refrigerated storage recommendations for the leaves include:

- 0°C and 90–95% r.h. for 1–2 months (Lutz and Hardenburg 1968).
- $0\text{--}1^\circ\text{C}$ and 85–90% r.h. for 1–2 weeks (Amezquita Garcia 1973).
- $0\text{--}1^\circ\text{C}$ and 95–100% r.h. for 1–2 months (Snowdon 1991).
- $18\text{--}20^\circ\text{C}$ with 85–90% r.h. for 3 days (Lisiewska *et al.* 1997).

The taproot of Hamburg parsley can be stored for several months at 0°C and 90–95% r.h. (Lutz and Hardenburg 1968).

Controlled atmosphere storage

CA storage recommendations for the leaves include:

- 5°C with 10% O_2 + 11% CO_2 was optimal for delaying yellowing (Apeland 1971).
- 0°C with 5% CO_2 and 21% O_2 delayed chlorophyll degradation (Aharoni *et al.* 1989).
- 10% O_2 + 10% CO_2 (Yamauchi and Watada 1993).
- 0°C with 8–10% O_2 + 8–10% CO_2 (Saltveit 1997).
- 10% CO_2 delayed yellowing at room temperature (Lers *et al.* 1998).

Modified atmosphere packaging

Desiccation was the most important cause of postharvest loss and storage in folded, unsealed, PE bags at 1°C combined with pre-cooling gave a maximum storage life of about 6 weeks. If desiccation occurred placing the petioles in water enabled them to recover from a maximum of 10% loss (Almeida and Valente 2005). Aharoni *et al.* (1989) showed that non-perforated PE liners delayed yellowing and decay during low-temperature storage. In $40 \mu\text{m}$ thick ceramic film Park and Kwon (1999) found that they could be stored for 77 days at 0°C or 35 days at 5°C , with good retention of firmness and vitamin C content. In an experiment green tops were bunched, with 25–30 g per bunch, packed in perforated or non-perforated PE bags ($20 \times 25 \text{ cm}$) and stored at 2, 5, 10, 15 or 20°C . The tops stored better in non-perforated than in perforated bags and the longest satisfactory storage of 14–21 days

was in non-perforated bags at 2 °C. The non-packed bunches kept well for 1–2 days at 2 °C but deteriorated rapidly at the higher temperatures (Umiecka 1973). Sirivatanapa (2006) found that in storage in Thai ambient conditions they had a shelf life of 3–5 days while in modified atmosphere packaging and storage at 1–2 °C they had a shelf life of 14 days and retained their fresh green colour.

Hypobaric storage

It was reported that hypobaric conditions extended their storage life from 5 weeks in cold storage to 8 weeks without appreciable losses in protein, ascorbic acid or chlorophyll content, while storage in atmospheric pressure resulted in high losses (Bangerth 1974).

Transport

Aharoni *et al.* (1989) studied freshly harvested parsley under simulated conditions of air transport from Israel to Europe, as well as with an actual shipment, during which temperatures fluctuated between 4 and 15 °C. Packaging in perforated polyethylene-lined cartons resulted in a marked retardation of both yellowing and decay.

Table 160 The composition of rosemary for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	67.77 g	Total ascorbic acid	21.8 mg
Energy	131 kcal	Thiamine	0.036 mg
Protein	3.31 g	Riboflavin	0.152 mg
Total lipid (fat)	5.86 g	Niacin	0.912 mg
Carbohydrate, by difference	20.70 g	Vitamin B-6	0.336 mg
Total dietary fibre	14.1 g	Folate	109 µg_DFE
Calcium	317 mg	Vitamin B-12	0.00 µg
Iron	6.65 mg	Vitamin A	146 µg_RAE
Magnesium	91 mg	Vitamin A	2924 IU
Phosphorus	66 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	668 mg	Vitamin D	0 IU
Sodium	26 mg	Fatty acids, total saturated	2.838 g
Zinc	0.93 mg	Fatty acids, total monounsaturated	1.160 g
		Fatty acids, total polyunsaturated	0.901 g

Diseases

Erwinia and *Botrytis* have been reported to cause postharvest damage in parsley (Ryall and Lipton 1979).

Rosemary

Labiatae, Lamiaceae

Rosmarinus officinalis L. It is native to the Mediterranean region but is widespread throughout temperate regions where it is used both as an ornamental and a culinary herb. It is an evergreen subshrub with erect branches whose leaves are downy when young. The chemical content was given by USDA Nutrient Database (2012a) in Table 160. Storage at 0 °C and 90–95% r.h. for 2–3 weeks was recommended by Cantwell (1997) and Wright (2002).

Sage

Labiatae, Lamiaceae

Salvia officinalis L. It is native to the Mediterranean region, but has long been cultivated throughout Europe. It is a perennial subshrub, with a tap root and hairy stems. Respiration rate was reported to be 36 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 103 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 157 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Wright 2002). Recommended storage conditions were 0 °C and 90–95% r.h. for 2–3 weeks (Cantwell 1997, Wright 2002).

Summer savoury

Labiatae, Lamiaceae

Satureja hortensis, *S. montana* L. also simply called savoury. It originated in the eastern Mediterranean and has been used in Britain from the Saxon times. The leaves are used for seasoning foods but principally for beans and is known in Germany as bohnenkraut the bean herb (Loewenfeld 1964). It is an annual bushy tender herb, up to 30 cm tall with dark green leaves. Bottcher *et al.* (2000) showed that freshly harvested leaves of the cultivar Aromatawas have a high respiration rate of 696 W tonne⁻¹ at 10 °C, 1578 W tonne⁻¹ at 20 °C and 2536 W tonne⁻¹ at 30 °C. The values declined only by 49, 46 and 41%

of the initial rate for each temperature range over an 80-h storage period. Their high respiration rate resulted in high storage losses. At 10 °C they lost 1.65% in fresh weight in 24 h. It was found that their colour and exterior quality were best maintained by dehydration and storage in relative cool conditions.

Tarragon

Asteraceae, Compositae

Artemisia dracunculus L. It is widely distributed extending from Eastern Europe through Siberia, Mongolia, China and North America where it is used as a culinary herb. It is a perennial plant with erect leafy stems and rhizomes. Respiration rate was reported to be 40 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 99 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 234 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Wright 2002). Storage at 0 °C with 90–95% was recommended (Cantwell 1997, Wright 2002).

Thyme

Labiatae, Lamiaceae

Thymus vulgaris L., also called garden thyme. It is native to the Mediterranean region but it is widely grown elsewhere as a culinary and medicinal herb. The chemical content was given by USDA Nutrient Database (2012a) in Table 161. Respiration rate was reported to be 38 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 82 mg CO₂ kg⁻¹ h⁻¹ at 10 °C and 203 mg CO₂ kg⁻¹ h⁻¹ at 20 °C (Wright 2002). Storage at 0 °C and 90–95% r.h. for 2–3 weeks was recommended (Cantwell 1997, Wright 2002).

Turmeric

Zingiberaceae

Curcuma domestica, *C. longa*. It is a tropical plant native to southern and south-eastern tropical Asia (Aggarwal *et al.* 2005). Purselove (1972) stated that it appears to have originated in deciduous monsoon forests but is not known in its wild state. It has become cultivated in southern and Southeast Asia up to 2000 m with annual rainfalls of 1000–2000 mm since it requires irrigation below 1000 mm. Its optimum temperature for growth is 20–30 °C. Turmeric

Table 161 The composition of thyme for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	65.11 g	Total ascorbic acid	160.1 mg
Energy	101 kcal	Thiamine	0.048 mg
Protein	5.56 g	Riboflavin	0.471 mg
Total lipid (fat)	1.68 g	Niacin	1.824 mg
Carbohydrate, by difference	24.45 g	Vitamin B-6	0.348 mg
Total dietary fibre	14.0 g	Folate	45 µg_DFE
Calcium	405 mg	Vitamin B-12	0.00 µg
Iron	17.45 mg	Vitamin A	238 µg_RAE
Magnesium	160 mg	Vitamin A	4751 IU
Phosphorus	106 mg	Vitamin D (D2 + D3)	0.0 µg
Potassium	609 mg	Vitamin D	0 IU
Sodium	9 mg	Fatty acids, total saturated	0.467 g
Zinc	1.81 mg	Fatty acids, total monounsaturated	0.081 g
		Fatty acids, total polyunsaturated	0.532 g

has been used in India for over 2500 years and is a major part of the Ayurvedic system of medicine. It was first used as a dye and then later for its medicinal properties (Herbs List n.d.). Turmeric is widely consumed in the countries of its origin for a variety of uses, including as a dietary spice and an Indian folk medicine for the treatment of various illnesses (Aggarwal *et al.* 2005). Turmeric is an important constituent of curries throughout the world.

It is a perennial herb up to 1 m tall with a short stem and tufted leaves. It belongs to the ginger family. The primary tuber bears 5–8 rhizomes up to 5 cm long. These are straight or slightly curved and have secondary branches in two rows at right angles that may have tertiary branches forming a dense clump. The rhizomes are brownish and scaly with orange flesh (Purselove 1972).

Harrison *et al.* (1985) stated that their rhizomes contain 30–40% starch. Purselove (1972) gave the composition of the rhizomes as approximately 13.1% water, 69.4% carbohydrate, 6.3% protein, 5.1% fat, 3.5% ash and 2.6% fibre. Turmeric is a potent antioxidant and contains aromatic oils, which are mainly terpenes and the main colouring material are curcuminoids. Perhaps the most active component is curcumin, which may make up 2–5% of the total spice in turmeric. Curcumin is a diferuloylmethane and its structure was first described in 1815 by Vogel

and Pellatier and in 1910 was shown to be diferuloylmethane (Aggarwal *et al.* 2005). Harvesting is usually 9–10 months after planting when the lower leaves turn yellow (Purseglove 1972). The rhizomes are dug carefully by hand.

White mustard

Brassicaceae, Cruciferae

Brassica juncea (L.) Czerniak, *B. alba*, also simply called mustard. The plants are grown only to the seedling stage and the whole plant is eaten in salads often combined with cress seedlings (*Lepidium*

sativum). They are also grown for their mature seeds, which may be dried, ground and blended with other species to produce table mustard. Mustard seedlings are usually harvested some 6 days after sowing (Purseglove 1968) before they become bitter and tough (Pantastico 1975).

Winter savoury

Labiatae, Lamiaceae

Satureja montana also called Savoury. It is a native of southern Europe and northern Africa. It is a hardy perennial shrub up to 30 or 40 cm tall.

6

Specific recommendations for mushrooms and other fungi

Introduction

A wide range of fungal fruiting bodies are eaten. These include:

- *Agaricus arvensis* Field Mushroom and Horse Mushroom
- *Agaricus augustus* Prince
- *Agaricus bisporus* known variously as the Common Mushroom, Button Mushroom, White Mushroom, Table Mushroom, Champignon Mushroom, Crimini Mushroom, Swiss Brown Mushroom, Roman Brown Mushroom, Italian Brown, Italian Mushroom and Portobello.
- *Agaricus campestris* Field Mushroom
- *Boletus edulis* Penny Bun Bolete, Cep or Porcini
- *Calvatia* (*Langermannia*) *gigantea* Common Puffball
- *Cantharellus cibarius* Summer Chanterelle or Girolle
- *Cantharellus tubaeformis* Autumn Chanterelle or Yellow Legs
- *Macrolepiota procera* Parasol Mushroom
- *Morchella elata* and *Morchella esculenta* Morels.

Some 80 species of mushroom have been cultivated for consumption with *A. bisporus* being the first to be developed. This was by Melon growers near Paris in France during 19th century (Nichols 1992). Total

world production for mushrooms and truffles in 2010 were estimated by FAO (2012) as 7,397,558 tonnes. No information could be found on the postharvest life of many edible mushrooms and fungi but from the literature it would appear that all types of edible mushrooms have similar storage requirements. Where no specific information is available the recommendations for the cultivated mushroom (*A. bisporus*) could be followed.

Beefsteak fungus

Fistulinaceae

Fistulina hepatica. It is a bracket fungus up to about 30 cm across and 7 cm thick and feels soft, moist and sticky. When cultivated in China the mature basidiocarps weighed 60–80 g and the pilei were 10–16 cm in diameter (Huang 1996). It is tongue- or kidney-shaped and blood red in colour darkening as it ages with red flesh that oozes a red fluid when cut. It contains tannic acid and therefore should be soaked before cooking. It has whitish pores turning dark red with reddish brown spores. It grows parasitically on deciduous trees, particularly oak, usually near the base. Infection causes brown heart rot resulting in the wood being stained, but infection can also be lethal to the tree.

Yanagimatsutake mushrooms

Strophariaceae

Agrocybe cylindracea. It is a basidiomycete gill fungus and grows on clumps of poplar and willow and has a cap of up to 10 cm diameter, is pale buff in colour, darkening towards the centre. The gills are brown and the stem has a ring and is pale buff in colour.

Blewit

Tricholomataceae

Lepista saeva, also called field blewit. It is a gill fungus with a cap diameter of up to 10 cm and a height of up to 8 cm, and has a mealy smell and a mild flavour. The cap is domed as it emerges and gradually flattens and may become depressed in the centre with a wavy margin and has a dry smooth surface. It is pale brown in colour becoming darker towards the centre. The gills are buff in colour with pink spores. The stalk has a very bulbous base and is white sometimes streaked and lined with an intense lilac colour. It is commonly found in grassy areas and deciduous woods and may be found growing in large circles in autumn. It is said to cause stomach upsets in some people, but otherwise it is delicious.

Cep

Boletaceae

Boletus edulis (Bull.: Fr.). Other common names include penny bun boletus or c pe also king bolete in the United States and porcini in Italy. Other boletes include *B. satanas*, *B. badius*, *Suillus luteus*, *S. bovinus*, *Leccinum scabrum* and *Strobilomyces strobilaceus* (synonymous with *S. floccopus*). Some boletoid fungi have gills, for example *Gomphidius roseus*, *Chroogomphus rutilus* and *Hygrophoropsis aurantiaca*. The cap of this edible fungus is up to 20 cm in diameter and 20 cm high and is hemispherical as it emerges becoming more rounded and flattened as it develops. It tends to have a slippery surface when wet and its colour is a rich chestnut-brown becoming darker towards the centre and can have narrow white margins with white flesh and a nutty aroma. It has a thick stalk that is white with a brown-netted pattern tapering from the base. It is common in August and September in deciduous woodland, especially beech

woods, but is also found in coniferous woods. At one time it was used commercially for some canned mushroom soup in Britain instead of the cultivated mushroom because of its superior flavour and texture when cooked. However it ceased to be used because application of the Trade Description Act insisted that it should be called *Boletus* soup, a name that apparently did not appeal to marketing staff. Several other species, which have *Boletus* as their common name, are edible, including Bay Boletus (*Boletus badius*), Orange Birch Boletus (*Leccinum versipelle*), Brown Birch Boletus (*Leccinum scabrum*), Larch Boletus (*Suillus grevillei*) as well as other species of *Boletus* that have no common name including *B. appendiculatus*, *B. erythropus* and *B. luridus*.

Chantarelle

Cantharellaceae

Cantharellus cibarius (Fr.: Fr.) Fr. is closely related to *C. cornucopioides* horn of plenty. It is a bracket fungus. On emergence the cap is a flattened dome with a wavy margin. As it develops it expands and becomes funnel- or trumpet-shaped still with a wavy margin. The cap is a deep yellow-orange colour and has a smooth surface. On the underside of the cap it is wrinkled and yellow. The stem tapers towards the base and is also a yellow-orange colour. It is a delicious fungus, which is said to have a distinct smell of apricots when fresh. The chemical content was given by USDA Nutrient Database (2012a) in Table 162.

They are harvested by hand as soon as they are big enough and their shelf life in simulated room temperature of 20 °C and 60% r.h. was shown to be only 2–3 days (Mercantilia 1989). Refrigerated storage recommendations were 0 °C and 90% r.h. for 2 weeks (Mercantilia 1989) and 0 °C and 90–95% r.h. for 2 weeks (SeaLand 1991).

Crimini mushroom

Agaricaceae

Agaricus bisporus (Lange.) Sing. also called brown mushroom and Italian mushroom. The chemical content was given by USDA Nutrient Database (2012a) in Table 163. Stamets (2005) reported 33.48 g 100⁻¹

protein, 2.39 g 100⁻¹ fat and 46.17 g 100⁻¹ carbohydrate on a dry weight basis.

Table 162 The composition of chanterelle fungi for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.85 g	Phosphorus	57 mg
Energy	38 kcal	Potassium	506 mg
Protein	1.49 g	Sodium	9 mg
Total lipid (fat)	0.53 g	Zinc	0.71 mg
Carbohydrate, by difference	6.86 g	Thiamine	0.015 mg
Total dietary fibre	3.8 g	Riboflavin	0.215 mg
Sugars, total	1.16 g	Niacin	4.085 mg
Calcium	15 mg	Vitamin B-6	0.044 mg
Iron	3.47 mg	Folate	2 µg_DFE
Magnesium	13 mg	Vitamin D (D2 + D3)	5.3 µg
		Vitamin D	212 IU

Table 163 The composition of crimini mushroom for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.12 g	Thiamine	0.095 mg
Energy	22 kcal	Riboflavin	0.490 mg
Protein	2.50 g	Niacin	3.800 mg
Total lipid (fat)	0.10 g	Vitamin B-6	0.110 mg
Carbohydrate, by difference	4.30 g	Folate	25 µg_DFE
Total dietary fibre	0.6 g	Vitamin B-12	0.10 µg
Sugars, total	1.72 g	Vitamin A	0 µg_RAE
Calcium	18 mg	Vitamin A	0 IU
Iron	0.40 mg	Vitamin E (α-tocopherol)	0.01 mg
Magnesium	9 mg	Vitamin D (D2 + D3)	0.1 µg
Phosphorus	120 mg	Vitamin D	3 IU
Potassium	448 mg	Vitamin K (phylloquinone)	0.0 µg
Sodium	6 mg	Fatty acids, total saturated	0.014 g
Zinc	1.10 mg	Fatty acids, total monounsaturated	0.002 g
Total ascorbic acid	0.0 mg	Fatty acids, total polyunsaturated	0.042 g

Enoki-take mushrooms

Physalacriaceae

Flammulina velutipes. Other common names include winter mushroom and velvet shank. It is an edible

gill fungus. As it emerges from the dead wood on which it grows the cap is conical, but it expands and flattens as it develops. The cap is bright yellow to orange in colour, often darker in the centre when it is wet, and it develops an undulating sticky surface. The gills are yellow and the spores are white. The flesh is yellowish. The stem is tough and an orange brown in colour, darkening, curving and becoming velvety towards the base. They are common in the wild on dead tree stumps throughout Europe and are grown commercially in Japan, United States and Korea.

Storage

Inaba *et al.* (1989) found that there was no response in respiration rate to ethylene at 100 µl L⁻¹ for 24 h at any temperature between 5 and 35 °C. Shelf life was shown by Minamide *et al.* (1980a) to be approximately 14–20 days at 1 °C, 10 days at 6 °C and only 2–3 days at 20 °C. Browning of the pilei, gills and stipes and polyphenoloxidase activity were markedly increased during storage at 20 °C (Minamide *et al.* 1980a). In storage where the temperature fluctuated from the average 6 °C by ±5, 3 or 1 °C every 12 or 6 h. Ito and Nakamura (1985) found that fluctuating temperature had a particularly marked detrimental effect on the quality.

Modified atmosphere packaging

In Japan and the United States they are vacuum-packed in polyethylene film for retail sale (Malizio and Johnson 1991). The effect of polyvinylidene-chloride-coated, oriented nylon, antifogging, wrap or vacuum packing film at 25 or 2 °C was investigated. The best treatment for maintaining quality was packing in antifogging film where they could be stored for 28 days at 2 °C (Chi *et al.* 1998). At 0 °C in sealed PE bags they were successfully stored for up to 15 days (Chi *et al.* 1996). LDPE film 30 µm thick and embedded with silver-coated ceramic extended storage life from 10 days in LDPE film without ceramic to 14 days at either 5 or 20 °C. After 14 days' storage at 5 °C, O₂ and CO₂ concentrations were 7.3 and 8.6%, respectively, in the LDPE film package without ceramic, and 2.9 and 11.6%, respectively, in the silver-coated ceramic LDPE film (Eun *et al.* 1997).

Vacuum packaging did not improve their storage life over packing in PE bags (Kang *et al.* 2001).

Packaging in polyolefin film bags containing 100 g of mushrooms established an equilibrated atmosphere of 1.7–2.4% O₂ and 4.1–5.6% CO₂ inside the package at 10 °C and improved their storage life. The gas permeability of the film was 166 and 731 ml m⁻² h⁻¹ atm.⁻¹ for O₂ and CO₂, respectively. Temperature fluctuations between 5 and 15 °C did not induce a harmful atmosphere inside the polyolefin package, though high temperatures accelerated the quality loss (Kang *et al.* 2001).

Fairy ring toadstool

Marasmiaceae

Marasmius oreades. It is a basidiomycete gill fungus with a cap diameter of up to 6 cm and up to 10 cm high. As the sporophore forms it has a pronounced bulge that flattens and expands with age. The cap is tan-coloured and often grooved at the margins, it has white flesh and the gills are brownish and the spores white. It often grows wild in large rings, hence its common name and is commonly found in grassy places. The stem is tough and pale brown and woolly towards the base. In Japan Tanesaka *et al.* (1993) found that the vegetative mycelia, which seemed to be differentiated from the fruit bodies of *Marasmius* spp., formed small colonies on leaf litter. Vetter (2003) found that *M. oreades* was an important protein source with a mean value of 52.8% of its dry weight.

Field mushroom

Agaricaceae

Agaricus campestris. It is closely related to the cultivated mushroom *A. bisporus* and can be distinguished by the thin ring on the stalk when the cap has opened.

Grey knight or dirty tricholoma

Tricholomataceae

Tricholoma terreum (Schaeff.: Fr.) Kummer is a grey-capped edible mushroom commonly known as, due to its discoloured gills. The cap is 4–7 cm wide and is covered in fine grey scales. Cap is also convex with a low broad umbo, light to dark grey

downy to felty. The stipe is 3–8 cm high and 1.5 cm wide, without ring or volva. The flesh is whitish grey, thin and easily broken. The gills are widely spaced and unattached to the stipe. It is regarded as a good edible mushroom with pleasant mild smell and taste (Kibar and Peksen 2011). Their chemical content was given by Song and Wang (2009) as 8.2% ash, 18.0% proteins, 8.8% fats, 19.8% cellulose, 60.0% carbohydrate, 2.4% common sugar and 730 mg Fe, 139 mg Zn, 19.2 mg Cu, 15.7 mg Mn in every 100 g dry weight.

Horn of plenty

Cantharellaceae

Craterellus (Cratarellus) cornucopioides. It is a bracket fungus with a cap diameter of up to 8 cm and a height of up to 10 cm. The cap is irregular and funnel-shaped with a wavy margin and is grey brown in colour and grey and slightly ribbed on the underside. The stalk is short and stout, tapering towards the base. In a comparison of eight species on edible mushrooms Vetter (2003) found that *C. cornucopioides* was among the low-protein species that were tested.

Horse mushroom

Agaricaceae

Agaricus arvensis. It is stout with a cream to off-white cap that may become stained with yellow as it becomes over mature. It is globular when it first appears, but as it develops the vale is broken leaving a shallow dome and gills that are white, then change to pink and finally to brown. The stem is off-white and thick and tapers to the base and has two distinctive rings where the vale was attached.

Jew's ear

Auriculariaceae

Auricularia polytricha, *A. auricula-judae*, *Hirneola auricula-judae* also called black ear mushroom. It is a jelly fungus and has a rubbery texture, but is cultivated and eaten in China and is also used medicinally to cure sore throats and inflamed eyes. It is reddish brown in colour and can be almost

translucent. It is usually found growing on branches of elder (*Sambucus nigra*). As the common name implies it resembles a human ear and the name is a corruption of Jude's ear since traditionally in the Christian religion Jude was supposed to have hanged himself on an elder tree. It should be harvested while still young because as it matures it darkens in colour and becomes hard.

Maitake

Meripilaceae

Grifola frondosa also called hen of the woods. It is a bracket fungus and grows in oak and beech woods. It is cultivated in Japan where bag culture is the most frequently used system. Sawdust is mixed with rice and wheat bran. After adjustment of the moisture content, the mixture is packed in a polypropylene bag and is moulded into a square-shaped culture bed. Log and outdoor bed culture are also used. Mizuno (2000) found that low-temperature storage was more effective in maintaining their quality and the contents of anti-tumour polysaccharides as health beneficial foods. Both quality and polysaccharides deteriorated quickly during storage at 20 °C.

Milky mushroom

Tricholomataceae

Calocybe indica are native to tropical India with optimum production conditions of 25–28 °C and 75–84% r.h. (Trivedi *et al.* 1991). Commercial production in India dates from the 1970s and Krishnamoorthy (2004) reported that they have a shelf life of 5–7 days at room temperature.

Morels

Morchellaceae

Morchella esculenta. It is a cup fungus with a variable-shaped head from rounded to irregular oval and up to 20 cm high. There is a honeycomb of ridges on the surface with deep pits that are brown to olive green in colour. The head is usually hollow giving them a sponge-like feel. The stem is stout, white, hollow and often swollen towards the base. They

are delicious and much prized and can be found in northern Europe growing wild in grassy woodlands and chalky soils in spring (Sterry 1995). Related species include *M. vulgaris*, *M. rotunda*, *M. deliciosa*, *M. elata* and *M. crassipes* and the black morel *M. angusticeps*. A histocytological study showed that hyphae of *M. rotunda* were associated with all parts of the root system of Norway spruce (*Pinus abies*) in a plantation near Strasbourg in France. A mycelial sheath surrounds the main suberised roots. Finer rootlets are enveloped in a cottony mycelium and their absorbing root tips are ectomycorrhizal. Morel hyphae also invade older parts of a heterobasidiomycete ectomycorrhiza (Buscot and Kottke 1990).

Mushrooms

Agaricaceae

Agaricus bisporus (Lange) Sing., also called cultivated mushroom and button mushroom. It was first described by Mordecai Cubitt Cooke in his 1871 as *Agaricus campestris* var. *hortensis*. Jakob Emanuel Lange later called it *Psalliota hortensis* var. *bispora* in 1926. In 1938 it was renamed *Psalliota bispora*. The genus *Psalliota* was renamed to *Agaricus* in 1946 and Emil Imbach gave it the name of *Agaricus bisporus*, the species name *bispora* distinguished the two-spored basidiomycetes from four-spored basidiomycetes. The edible part is a sporophore, which is a fungal fruiting body that will freeze at about –1.2 to –0.9 °C (Wright 1942). The chemical content was given by USDA Nutrient Database (2012a) in Table 164 and Hammond and Nichols (1975) found that mannitol was the major carbohydrate with 13% d.w. Hammond (1979) reported a decrease in non-structural polysaccharides from 10 to 5% after 4 days of storage and an increase of 50% in chitin content of cell walls. The total sugars, soluble proteins and total phenol content during storage declined, while there was an increase in the PPO activity (Rai and Saxena 1989).

Preharvest factors

Addition of calcium chloride to irrigation water increased calcium content and improved quality of mushrooms independent of inherent calcium

Table 164 The composition of white mushrooms for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	92.45 g	Thiamine	0.081 mg
Energy	22 kcal	Riboflavin	0.402 mg
Protein	3.09 g	Niacin	3.607 mg
Total lipid (fat)	0.34 g	Vitamin B-6	0.104 mg
Carbohydrate, by difference	3.26 g	Folate	17 µg_DFE
Total dietary fibre	1.0 g	Vitamin B-12	0.04 µg
Sugars, total	1.98 g	Vitamin A	0 µg_RAE
Calcium	3 mg	Vitamin A	0 IU
Iron	0.50 mg	Vitamin E (α-tocopherol)	0.01 mg
Magnesium	9 mg	Vitamin D (D2 + D3)	0.2 µg
Phosphorus	86 mg	Vitamin D	7 IU
Potassium	318 mg	Vitamin K (phyloquinone)	0.0 µg
Sodium	5 mg	Fatty acids, total saturated	0.050 g
Zinc	0.52 mg	Fatty acids, total monounsaturated	0.000 g
Total ascorbic acid	2.1 mg	Fatty acids, total polyunsaturated	0.160 g

content (Varoquaux *et al.* 1999). Hartman *et al.* (2000) also showed that significant improvements in mushroom quality resulted from addition of 0.3% calcium chloride to the irrigation water. This practice resulted in about a twofold increase in calcium content, improved initial whiteness at harvest and reduced postharvest browning compared to untreated controls. They were also more resistant to the negative effects of excessive handling or bruising, but the calcium chloride treatment slightly reduced crop yield. Sodium selenite added to the irrigation water increased mushroom resistance to postharvest browning and enhanced their nutritional value, but the treatment decreased solids content. When calcium chloride and sodium selenite were both added, the positive effects remained and all these negative trends were reversed.

Oms-Oliu *et al.* (2010) found that exposure to pulsed light at doses of 4.8 J cm⁻² could extend the shelf life of fresh-cut mushrooms without significantly affecting their texture and antioxidant properties. Higher doses were found to inflict thermal

damage resulting in softening and browning due to an increase in PPO activity.

Harvesting

Mushrooms should be harvested when they reach a size that is acceptable to the market, but while the velum is still unbroken. For certain markets the sporophore is allowed to open fully with the velum broken, the cap extended and the stalk elongated. Care must be taken not to damage or detach immature sporophores during harvesting. The strain U1 was harvested 2 days and 1 day before the planned commercial harvesting date, on the commercial harvesting date and 1 day later by Braaksma *et al.* (1999). The earlier the mushrooms were harvested the less cap opening occurred during subsequent storage for 3 days at 20 °C and over 90% r.h. The smallest mushrooms, with a cap diameter of 1.5–2 cm, showed no cap opening during storage, irrespective of harvesting date. Mushrooms within one size class but harvested on different days were similar in size and appearance at the time of harvest but cap opening occurred in a larger proportion of the later harvested mushrooms and was completed earlier during storage.

A harvesting machine for mushrooms has been developed using robotics by Tillet and Reed (1990). This method uses a sucker end-effector that attaches to the cap of the mushroom and gently pulls it from the bed without damaging it (Figure 73). An image-processing algorithm that finds and selects the mushroom to be harvested on the basis of data with which it has been provided guides the robot (Tillet and Batchelor 1991). There are problems with this method, particularly where mushrooms are touching or growing out at acute angles to the bed surface. The development of neural networks with trainable algorithms can be used to overcome this and other image-processing challenges.

Pre-cooling

Varszegi (2003) compared forced wet cooling and vacuum cooling and found that vacuum cooling provided the longest period of time needed to reach the maximum value of microbial population and this method was found beneficial for the quality. Baker *et al.* (1981) observed that in button mushrooms, forced air cooling resulted in a weight loss

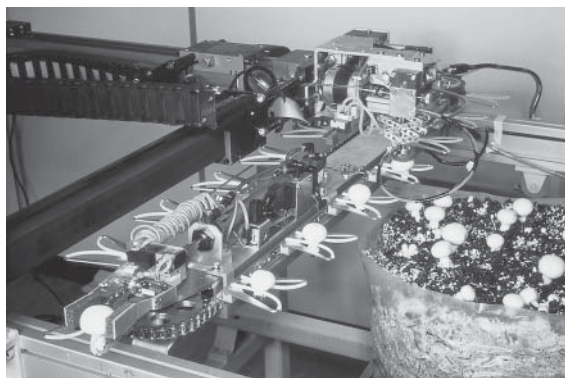


Figure 73 Robotic mushroom harvester developed at the Silsoe Research Institute in United Kingdom. (Photo: R. Tillet.)

of about 2.5% within 15–30 min. Minamide *et al.* (1985) recommended hydrocooling of button mushroom near their freezing point for 3 h within 6 h of harvesting.

Prestorage treatments

Nerya *et al.* (2005) reported that postharvest browning may be initiated by enzymatic oxidation of phenols such as tyrosine, to form brown pigments (melanin) or by non-enzymatic phenol oxidation induced by different factors, including bacteria. They found that pretreatment with 5% H_2O_2 prevented intact cap browning during 10 days subsequent storage at 4 °C and resulted in an immediate decrease in the number of colony forming units from 491 to 0.37 CFU cm^{-2} .

Enhancement in shelf life of *A. bisporus* up to a period of 10 days was achieved by application of γ rays close to 2 kGy and storage at 10 °C (Lescane 1984). Irradiation reduced the incidence of fungal and bacterial infection and also retarded the breakdown of mannitol and trehalose. However the loss of flavour of mushrooms has been reported after γ irradiation and irradiation at lower levels proved better than irradiation levels of 1 and 2 kGy (Roy and Bahl 1984a, 1984b). Ultraviolet C (UV-C) radiation could potentially be used for sanitizing fresh button mushrooms and extending their shelf life during storage at 4 °C for 21 days. Results showed that UV-C doses of 0.45–3.15 kJ m^{-2} resulted in 0.67–1.13 log CFU g^{-1} reduction of *Escherichia coli* O157:H7 inoculated on mushroom cap surfaces. UV-C radiation also

reduced total aerobic plate counts by 0.63–0.89 log CFU g^{-1} on the surface of mushrooms (Guan *et al.* 2012). Lagnika *et al.* (2013) reported that pretreatment with ultrasound and high-pressure argon affected losses during storage at 4 °C for 9 days. Mass losses were 3.01% for those treated with high-pressure argon, 5.09% for ultrasound, 5.39% for the combination of high-pressure argon and ultrasound and 9.59% for those not treated. Mushrooms from all three treatments retained their colour better than those that had not been treated.

Harvested mushrooms were coated with different gum-based coatings, including alginate and alginate-ergosterol, with or without emulsifier. Coated mushrooms had a better appearance, a better colour, and an advantage in reduced weight loss in comparison with non-coated ones. The alginate-ergosterol-Tween coating combination was most suitable for maintaining the size and shape of coated mushrooms (Hershko and Nussinovitch 1998).

Postharvest physiology

Hammond and Nichols (1975) gave their respiration rate at 28.2–43.6 $\text{mg CO}_2 \text{ kg}^{-1} \text{ f.w. h}^{-1}$ at 0 °C and Nichols (1985) gave 280 $\text{mg CO}_2 \text{ kg}^{-1} \text{ f.w. h}^{-1}$ at 19 °C. The respiration rates of samples of harvested mushrooms of the strain X25 held in air at 10 °C for 24 h ranged from 1.0 to 2.25 $\text{mmol kg}^{-1} \text{ h}^{-1}$, averaging 1.6 $\text{mmol kg}^{-1} \text{ h}^{-1}$. Respiration rate remained constant in mushrooms stored in open punnets at 1 °C with 95% r.h. for 4 days but increased linearly in mushrooms stored in open punnets at 10 °C and 90% r.h. for 4 days, reaching about 3.1 $\text{mmol kg}^{-1} \text{ h}^{-1}$ (Varoquaux *et al.* 1999). They also reported that at 10 °C O_2 consumption was 17.8 $\mu\text{g kg}^{-1} \text{ s}^{-1}$ and at 0 °C it was 3.7 $\mu\text{g kg}^{-1} \text{ s}^{-1}$. Hammond and Nichols (1975) found that mannitol was the main respiratory substrate during storage of button mushroom. They also reported that the rate of loss of mannitol was sufficient to account for about half of the carbon respired. Maximum ethylene production occurred subsequent to veil-break as the gill colour changed from pink to brown followed by a decline as the fruit body sporulated and senesced (Wood *et al.* 1977). Other measurements of respiration rates are given in Table 165. Ethylene can stimulate the stalk to elongate and the cap to expand. In button mushrooms cap

Table 165 Respiration rates of mushrooms (*Agaricus bisporus*) at different temperatures (source: adapted from Suslow and Cantwell 1998b)

Temperature (°C)	mg CO ₂ kg ⁻¹ h ⁻¹
0	28–44
5	70
10	97
20	240–288

expansion may cause the veils, which join the cap to the stalk, to break and they cease to be button mushrooms.

Storage

The main deteriorative factors are weight loss resulting in shrivelling, cap greying, stalk elongation, breaking of the velum, water soaking and microbial infections. Storage of mushrooms at 18–20 °C resulted in reduction in protein with accumulation of free amino acids due to activated protease enzyme activity and decrease in free amino acids and cell wall glucan (Murr and Morris 1975a, 1975b, Hammond 1979, Rai and Saxena 1988). At room temperature of 20 °C and 60% r.h. it was claimed that they could be kept for only 1 day (Mercantilia 1989). However Minamide *et al.* (1980a) observed that the shelf life of button mushroom was about 14–20 days at 10 °C, about 10 days at 6 °C and 2–3 days at 20 °C. Also Thompson *et al.* (1977b) found little loss in quality occurred, other than dry matter loss, when they were stored at room temperature of about 25 °C for several days. Storage at 4 °C led to the greatest inhibition of microbial contamination, and washing in chlorinated water and incorporation of silica gel humidity absorber in the LDPE bags also decreased microbial contamination (Popa *et al.* 1999). The maturation and textural changes in button mushrooms were slower at 0 °C than at higher temperatures (Murr and Morris 1975a). Refrigerated storage recommendations were:

- 0–1 °C and 85–90% r.h. for 3–7 days (Anonymous 1967).
- 0 °C and 85–90% r.h. for 5 days (Phillips and Armstrong 1967, Anonymous 1968, Hardenburg *et al.* 1990).
- 4.4 °C for 2 days (Lutz and Hardenburg 1968).
- 10 °C for 1 day (Lutz and Hardenburg 1968).

- 0 °C and 95% r.h. for 10 days with 7.8% loss (Pantastico 1975).
- 0–2 °C and 85–90% r.h. (Nichols 1985).
- 2 °C for 3–5 days (Umiecka 1988).
- 0 °C and 90–95% r.h. for 7 days (Mercantilia 1989).
- 2 °C for 5 days (Mercantilia 1989).
- 4 °C for 4 days (Mercantilia 1989).
- 8 °C for 3 days (Mercantilia 1989).
- 12 °C for 2 days (Mercantilia 1989).
- 0 °C and 90–95% r.h. (SeaLand 1991).
- 0–1 °C and 95% r.h. for 7–9 days (Adamicki 2002).

Discolouration of the cap and the cut stalk can be a deteriorative factor in storage. Liu and Wang (2012) found that mushrooms stored at 2 °C for 12 days in a continuous flow of humidified 80% O₂ + 20% N₂ had no cap or cut surface browning and higher antioxidant activity compared to those in air.

Controlled atmosphere storage

High levels of CO₂ in storage can result in cap discolouration (Smith 1965). Storage recommendations included:

- 4.4 °C with 5–10% CO₂ (Lutz and Hardenburg 1968, Ryall and Lipton 1979).
- 0 °C and 95% r.h. with 10–20% CO₂ inhibited mould growth and retarded cap and stalk development; O₂ levels of less than 1% were injurious (Pantastico 1975).
- 0–5 °C with 10–15% CO₂ and 21% O₂ which had a fair effect but was of limited commercial use (Kader 1985, 1992).
- 0–5 °C with 10–15% CO₂ and 21% O₂ which had a moderate level of effect (Saltveit 1989).
- 0 °C and 90–95% r.h. with 10–15% CO₂ and 21% O₂ (SeaLand 1991).
- 8% O₂ and 10% CO₂ (Zheng and Xi 1994).
- 3–21% O₂ + 5–15% CO₂ (Saltveit 1997).
- 0 °C and 3% O₂ + 10% CO₂ for 12–15 days (Suslow and Cantwell 1998b).

Storage under low O₂ and high CO₂ inhibits cap opening and internal browning, but causes yellowing of the cap surface. Levels of less than 1% O₂ can favour growth of *Clostridium botulinum*, the development of off-odours and off-flavours, as well as cap opening and stipe elongation. For this reason, CA is not commonly used (Adamicki 2002).

Modified atmosphere packaging

Polyvinyl chloride overwraps on consumer-sized punnets (about 400 g) greatly reduced weight loss, cap and stalk development and discolouration especially when combined with refrigeration (Nichols 1971). Storage of mushrooms in modified atmosphere packaging at 10 °C and 85% r.h. for 8 days delayed maturation and reduced weight loss compared to those stored without packaging (Lopez Briones *et al.* 1993). Modified atmosphere packaging in microporous film delayed mushroom development especially when combined with cool storage at 2 °C (Burton and Twynning 1989). Storage in LDPE bags containing 3% O₂ with 5% CO₂, 5% O₂ with 5% CO₂, 1% O₂ with 5% CO₂ or 3% O₂ with 7% CO₂ at 4, 18 and 26–28 °C showed little effect of CO₂ level but storage was best under the lowest O₂ regime (Popa *et al.* 1999). Roy *et al.* (1995) reported that the optimum O₂ level in MAP to reduce cap development was 6% at 2–6% CO₂. Thompson *et al.* (1977b) found that there were no differences between mushrooms sealed in polyethylene films of 30, 25 or 15 µm thickness during storage at either 0 or 20 °C. De la Plaza *et al.* (1995) reported that where the atmosphere in PE packages was 10% O₂ + 7% CO₂ there was delayed loss of firmness but they observed changes in sugar, organic acids, yellowing and they had reduced quality at 18 °C after 8 days of storage at 3 °C. Chopra *et al.* (1985) recommended 25 µm thick PE bags with 0.5% perforations. Nichols (1985) reported that the overwrap films should be perforated to keep the O₂ levels above 4% to prevent anaerobiosis. In contrast Saxena and Rai (1988) reported the adverse effects of perforation of packs and found that, in storage at 5 °C, non-perforated 25 µm thick PP bags gave the best results.

Decreases in dry matter of modified atmosphere packaged mushrooms matched the theoretical carbon consumption calculated from the constant respiration rate. Reducing O₂ from 20 to 1% did not affect respiration rate at temperatures ranging from 5 to 20 °C. Glucose and glycogen were rapidly catabolised, whereas mannitol consumption began 3 and 8 days after harvest at 20 and 10 °C, respectively. It is concluded that no extension of mushroom shelf life was attained through modified atmosphere packaging, but that controlling humidity within the package may be more effective (Varoquaux *et al.* 1999).

Liu and Wang (2012) stored *A. bisporus* at 2 °C for 12 days in a continuous air flow of either humidified air or 80% O₂ + 20% nitrogen. Browning occurred in those in air, which was due to enhanced antioxidant and free radical scavenging enzyme activity, while browning was prevented in 80% O₂. Higher antioxidant activity was found in the mushrooms in 80% O₂ and they recommended that storage in 80% O₂ could be used for mushrooms to avoid browning.

Diseases

Bacterial blotch *Pseudomonas* spp. can become a problem during storage at temperatures above the optimum (Suslow and Cantwell 1998b). It generally begins as a surface discolouration on the caps and stipes during production, developing into a dark brown sunken or pitted lesion. Dobbin (2001) found a novel pathovar of *Pseudomonas tolaasii* in discoloured lesions, on the mushroom pilei on a commercial mushroom farm in Ontario. In pathogenicity tests on mushrooms the postharvest spotting symptom was typically reproduced in 1–7 days postharvest. Jobling (2000) reported that mushrooms exposed to eucalyptus oil and packaged in a paper bag inside a plastic bag stayed whiter and the total bacterial count on their surface showed that the eucalyptus oil vapour had reduced the growth of the bacteria that caused the browning of mushrooms.

Nameko

Strophariaceae

Pholiota nameko. It is a basidiomycete and is a popular mushroom in Asia, especially Japan where it is grown on logs or media such as rice bran, sawdust and wood chips. Although Oda *et al.* (1976) refers to production conditions where mycelium was not injured at –5 °C, but their resistance of mycelium to injurious microorganisms was found to be weakened by freezing. This may well have implications to postharvest situations. Shelf life was approximately 14–20 days at 1 °C, 10 days at 6 °C and 2–3 days at 20 °C. There was some browning of the pilei, gills and stipes and PPO activity was increased during storage at 20 °C. Total free amino acid content was also greatly increased in storage at 20 °C (Minamide *et al.* 1980a).

Oyster mushrooms

Pleurotaceae, Tricholomataceae

Pleurotus ostreatus (Jacq. Fr) Kumm. *P. florida* and *P. eryngii*, also called hiratake mushroom. The common name is derived from its appearance, which resembles an oyster shell. *Pleurotus* is an efficient lignin-degrading mushroom and can grow well on different types of lignocellulosic materials. The cap surface is smooth brown or bluish grey when they emerge and turn a pale brown at maturity. The gills are whitish and the spore mass lilac. The stem is short and stout arising almost directly from the host tree. Stamets (2005) gave their composition as protein 27.25 g 100 g⁻¹ d.w., fat 2.75 g 100 g⁻¹ d.w. and carbohydrates 56.61 g 100 g⁻¹ d.w. for Pearl oyster *P. ostreatus* and protein 19.23 g 100 g⁻¹ d.w., fat 2.70 g 100 g⁻¹ d.w. and carbohydrates 63.40 g 100 g⁻¹ d.w. for Phoenix oyster *P. pulmonarius* (*sajor caju*) with sugar 23.3 and 11.8 g 100 g⁻¹ f.w., respectively.

Prestorage treatment

Treatment with chitosan prolonged storage life to 10 days, 4 days longer than those packed in antifogging film (Cho and Ha 1998). In India postharvest application of lactic acid bacteria such as *Lactobacillus* could inhibit the growth of moulds on oyster mushrooms (Gogoi and Baruah 2000). Jafri *et al.* (2013) reported that pretreatment of oyster mushrooms with sorbitol (0.05%, w/v), citric acid (3%, w/v) or CaCl₂ (1%, w/v) followed by modified atmosphere packaging using 10% O₂ and 5% CO₂ provided better retention of quality characteristics and received higher sensory ratings compared to other samples, resulting in a storage life of 25 days at 4 °C.

Roy *et al.* (2000) reported that irradiation of oyster mushrooms was found to delay the development of the caps, stalks, gills and spores and also reduce the loss of water, colour and flavour. Irradiation of King oyster mushrooms with 1 kGy was most effective in extending their storage life in polystyrene trays covered with PVC film for 4 weeks at 5 ± 1 °C. Hunter L values (lightness) increased after irradiation and remained high throughout the storage period in the irradiated samples. Samples irradiated with 1 kGy maintained an overall better texture than those not

irradiated or those irradiated with 2 or 3 kGy (Akram *et al.* 2012).

Postharvest physiology

Villaescusa and Gil (2003) reported that their respiration rate was 20 µg CO₂ kg⁻¹ s⁻¹ at 0 °C, 39.6 µg CO₂ kg⁻¹ s⁻¹ at 4 °C and 49.2 µg CO₂ kg⁻¹ s⁻¹ at 7 °C.

Storage

Storage life was approximately 14–20 days at 1 °C, 10 days at 6 °C and 2–3 days at 20 °C. Browning of the pilei, gills and stipes and PPO activity and total free amino acid content were markedly increased during storage at 20 °C (Minamide *et al.* 1980a). Martinez Soto *et al.* (1998) reported that an important parameter for extending shelf life of fresh oyster mushrooms was maintaining a suitable humidity. Bohling and Hansen (1989) recommended a temperature of 1 or 3.5 °C for about 1 week. Storage at 8 °C resulted in mushrooms that were still acceptable but had lost colour and firmness. After 7 days at 15 °C the mushrooms were spoiled. During storage the hyphae can grow beyond the surface of the stem, cap and lamellae giving the impression of mould infection (Bohling and Hansen 1989, Henze 1989).

Controlled atmosphere storage

Controlled atmosphere storage at 1 °C and 94% r.h. with 30% CO₂ and 1% O₂ for about 10 days was recommended by Henze (1989). Controlled atmosphere storage was shown to have little effect on increasing storage life at either 1 or 3.5 °C but at 8 °C with a combination of 10% CO₂ and 2% O₂ or 20 or 30% CO₂ and 21% O₂ it was effective (Bohling and Hansen 1989). Ramanathan *et al.* (1992) reported that 15% CO₂ + 1% O₂ maintained their keeping quality for up to 20 days.

Modified atmosphere packaging

Packaging in LDPE films reduced transpiration and external browning, maintained a soft texture and general quality during storage at 5 or 10 °C for 9 days (Martinez Soto *et al.* 1998). Rai *et al.* (2000) successfully stored them at 5 and 15 °C, using highly permeable micro-perforated OPP film

and non-micro-perforated OPP film packages. The gas concentrations inside the packages went as low as 0.4% O₂ and CO₂ up to 12–13%. The effect of polyvinylidene-chloride-coated, oriented nylon, antifogging, wrap or vacuum packing in film before storage at 25 or 2 °C was investigated by Chi *et al.* (1998). The best treatment for maintaining quality was packing in antifogging film that increased storage life to 24 days at 2 °C. At 0 °C in sealed PE bags their storage life was only 15 days (Chi *et al.* 1996). Popa *et al.* (1999) found that storage at 4 °C led to the greatest inhibition of microbial contamination and washing in chlorinated water and incorporation of a silica gel humidity absorber in the LDPE bags also decreased microbial contamination.

Parasol mushrooms

Agaricaceae

Macrolepiota procera, *Lepiota procera*. It is a gill fungus of the order Agaricales, with a cap up to 14 cm in diameter and 16 cm high. The cap is a creamy white to brown colour covered in dark flaky scales. They are shaped like an organ stop as they emerge, eventually expanding to plate shape with white flesh. The gills are white and closely packed with white spores and a whitish stalk covered with darker scales in patches and a thick double ring. It is a native of grassy areas and tastes delicious.

Pink-spored grisette

Pluteaceae

Volvariella speciosa also called Rose-Gilled Grisette. It is a gill fungus with a cap diameter of up to 10 cm and a height of 10 cm. The cap surface is very sticky and pale grey-green to pale brown in colour darkening towards the centre with white flesh. The gills are dull orange or pink and closely packed together with pink spores. The stalk is whitish and tapers from the base, which is slightly bulbous and enclosed in a delicate cup-like volva that disintegrates easily when harvested. It is found growing in compost heaps, rotting straw bales and heavily manured pastures. They should be picked while they are still young because they have an unpleasant smell as they develop.

Portabello

Agaricaceae

Agaricus bisporus (Lange.) Sing. also called portabella. Portobello is an edible mushroom native to grasslands in Europe and North America. The chemical content was given by USDA Nutrient Database (2012a) in Table 166 and Stamets (2005) gave the sugar content as 22.70 g 100 g⁻¹ f.w. and protein 34.44 g 100 g⁻¹ d.w., fat 3.1 g 100 g⁻¹ d.w. and carbohydrates 47.38 g 100 g⁻¹ d.w.

Saffron milkcap

Russulaceae

Lactarius deliciosus. It is a gill fungus up to 10 cm in diameter and 8 cm high. As it emerges the cap is a flattened dome with a depressed centre and an inrolled margin, but as it expands it becomes more funnel-shaped. It is a saffron yellow colour with concentric rings of darker orange with a slightly sticky surface. The stalk is an orange-buff colour, often with darker coloured blotches. The flesh is milky and

Table 166 The composition of grilled portabella for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	90.66 g	Thiamine	0.072 mg
Energy	29 kcal	Riboflavin	0.403 mg
Protein	3.28 g	Niacin	6.255 mg
Total lipid (fat)	0.58 g	Vitamin B-6	0.122 mg
Carbohydrate, by difference	4.44 g	Folate	19 µg_DFE
Total dietary fibre	2.2 g	Vitamin B-12	0.00 µg
Sugars, total	2.26 g	Vitamin A	0 µg_RAE
Calcium	3 mg	Vitamin A	0 IU
Iron	0.40 mg	Vitamin E (α-tocopherol)	0.00 mg
Magnesium	13 mg	Vitamin D (D2 + D3)	0.3 µg
Phosphorus	135 mg	Vitamin D	14 IU
Potassium	437 mg	Vitamin K (phylloquinone)	0.0 µg
Sodium	11 mg	Fatty acids, total saturated	0.079 g
Zinc	0.65 mg	Fatty acids, total monounsaturated	0.011 g
Total ascorbic acid	0.0 mg	Fatty acids, total polyunsaturated	0.287 g

orange-yellow in colour turning green in places. The gills are orange-yellow with cream-coloured spores. It is found in coniferous woodland on chalky soils. Fernandes *et al.* (2012) studied the effects of γ radiation at 0, 0.5 and 1 kGy on *L. deliciosus* during storage for up to 8 days at 5 °C. They found that irradiation and cold storage did not significantly affect the physical properties but there was a slight decrease in redness in those that had been irradiated.

Shiitake

Agaricaceae

Lentinus edodes (Berk.) Singer, *Lentinula edodes* (Berk.) Peglar. Mizuno (1995) described some of the health properties. They contain a β -glucan called lentinan that was shown to have anti-tumour activity against lung carcinoma and two human melanomas probably by activating the host immune system. Preliminary studies also suggested that shiitake extracts possess hypolipidemic and antithrombotic activity. The cap is a greyish brown colour with a slender stalk and white gills. The chemical content was given by USDA Nutrient Database (2012a) in Table 167. Stamets (2005) reported 32.93 g 100⁻¹ protein, 3.73 g 100⁻¹ fat and 47.60 g 100⁻¹ carbohydrate dry weight.

Harvesting

They are grown on sticks and branches and are harvested by cutting the mushrooms from the sticks by hand. In China Liang *et al.* (2000) described a shiitake stalk-cutting machine, but they found problems in

operation and it had not been developed to the stage that it could be used commercially.

Prestorage treatment

Vacuum infiltration with calcium chloride solution at concentrations of 0.005, 0.01, 0.03, 0.06 and 0.09 μL^{-1} markedly inhibited respiration and ethylene production, decreased the loss of soluble solids, protein, reducing sugars, starch, organic acids, ascorbic acid and fibre; significantly restricted the increase of cell membrane permeability, and thus enhanced the quality of shiitake in storage. The best concentrations were 0.01, 0.03 and 0.06 μL^{-1} (Li *et al.* 2000).

Postharvest physiology

Shiitake showed no response to exposure to 100 μL^{-1} ethylene for 24 h at any temperature over the range of 5–35 °C (Inaba *et al.* 1989). Respiration rate at 20 °C was found to be 264–653 $\mu\text{L O}_2 \text{ g}^{-1} \text{ h}^{-1}$.

Storage

They are often preserved by drying, but fresh ones were said to be preferred to dehydrated ones (Lui *et al.* 1989). Shelf life was approximately 14–20 days at 1 °C, 10 days at 6 °C and 2–3 days at 20 °C. Browning of the pilei, gills and stipes and polyphenoloxidase activity were markedly increased during storage at 20 °C. Total free amino acid content was also greatly increased at 20 °C (Minamide *et al.* 1980a). Storage life in ambient conditions was 1–3 days. Storage at 5 °C was for 7 days (quoted by Pujantoro *et al.* 1993). During storage where the temperature fluctuated from the average 6 °C by ± 5 , 3 or 1 °C every 12 or 6 h, Ito and Nakamura (1985) found that fluctuating temperature quickly reduced their quality, with the greater effect with the wider fluctuations. Low-temperature storage is more effective in maintaining the quality and the contents of anti-tumour polysaccharides as health beneficial foods (Mizuno 2000).

Controlled atmosphere storage

Browning was low in samples stored in 10% CO₂ with 1% O₂ with ethanol vapour. From these results, it is

Table 167 The composition of shiitake for 100 g⁻¹ fresh weight (source: adapted from USDA 2012a)

Water	89.74 g	Phosphorus	112 mg
Energy	34 kcal	Potassium	304 mg
Protein	2.24 g	Sodium	9 mg
Total lipid (fat)	0.49 g	Zinc	1.03 mg
Carbohydrate, by difference	6.79 g	Thiamine	0.015 mg
Total dietary fibre	2.5 g	Riboflavin	0.217 mg
Sugars, total	2.38 g	Niacin	3.877 mg
Calcium	2 mg	Vitamin B-6	0.293 mg
Iron	0.41 mg	Vitamin D (D2 + D3)	0.4 μg
Magnesium	20 mg	Vitamin D	18 IU

suggested that the inhibition of browning results from endogenous ethanol accumulation under high CO₂ and low O₂ conditions (Gong *et al.* 1993). Pujantoro *et al.* (1993) studied 0 °C with 5, 10, 15 and 20% CO₂ and 1, 5 and 10% O₂ plus an air control and found 40% CO₂ and 1–2% O₂ at an unspecified temperature extended their storage life four times longer than those stored in air (Minamide *et al.* 1980b, Minamide 1981, quoted by Bautista 1990). At 5–80% CO₂ PPO activity was reduced and amino acids increased but fermentation also occurred, resulting in off-flavours after 2 days. Some volatiles, especially formaldehyde and ethyl alcohol, increased during storage in 100% CO₂ but on exposure to air these disappeared after 6 h. They also reported that storage at 20 °C with 2% O₂ resulted in a marked reduction in gill browning and PPO activity and a rise in free amino acid content.

Modified atmosphere packaging

Recommended MA packaging conditions for mushrooms were given by Ares *et al.* (2006) as 3–5% of O₂ and less than 12% of CO₂. The shelf life in non-sealed PE bags (20 × 26 cm × 30 µm thickness) was about 18 days at 1 °C, 14 days at 6 °C, 7 days at 15 °C and 4 days at 20 °C. For best results they should be held at about 1 °C for a short period immediately after harvest and then at a constant storage temperature. Shelf life at 20 °C was longest following pre-cooling at 1 °C for 24 h in hermetically sealed bags 80 µm thick and containing CO₂ instead of air (Minamide *et al.* 1980c). Storage at 5 °C within a composite paper/plastic bag with the inclusion of a natural substance to reduce the ‘peculiar smell’, prevent browning, reduce weight loss and loss of flavour for about 15 days was described by Lui *et al.* (1989). The concentration of ethanol in tissues of shiitake in PE film bags increased during storage at 20 °C to 15 mM after 6 days’ storage and there was a negative correlation between ethanol concentration and browning index (Gong *et al.* 1993). Jiang *et al.* (2010) reported that UV-C treatment resulted in maintenance of a high level of firmness during 15 days storage in MA packaging at 1 ± 1 °C and 95% r.h. and reduced the decrease in firmness during shelf life of 3 days at 20 °C. They also reported that the UV-C radiation enhances antioxidant capacity in shiitake mushrooms. Parentelli *et al.* (2007) reported that O₂ concentrations were usually kept at 1–5% in MA

packages but O₂ level should not be less than 1% to avoid anaerobic respiration as well as growth of pathogens. CO₂ concentrations should be high, but with mushrooms CO₂ levels higher than 12% can cause browning. Therefore Oliveira *et al.* (2012) recommended two perforations (or three perforations for sliced mushrooms) at 10 °C to avoid browning. Parentelli *et al.* (2007) also reported that in order to keep the gas composition within the recommended range, the optimum number of perforations should be one in storage at 0 or 5 °C, 3 at 10 °C and 10 at 15 °C using a 0.33-mm needle. This gave perforations per m² of 58, 174 and 349, respectively. At 0 °C, at least one perforation was required to avoid anoxia and hence possibility of anaerobic microorganisms growth such as *Clostridium botulinum*. The needle diameter used was too large to use at the lower temperatures; therefore a smaller needle diameter should be tested.

Straw mushrooms

Pluteaceae

Volvariella volvacea (Bull. Fr.) Singer, also called paddy straw mushroom and Chinese mushroom. It is a gill fungus. Other edible species include *V. esculenta*, *V. bombycina* and *V. speciosa*. It requires high temperature and humid conditions and grows in rice straw stacks in China where it has been cultivated for more than 300 years (Rajapakse 2011). The content of volatile flavour compounds accumulated steadily with maturation with more flavour compounds, including both aroma and taste compounds, in sporophores harvested when the stipe had elongated and the cap opened. In Nigeria it deteriorated quickly after harvest, but storage at 12 °C preserved their texture and nutrient composition for 1 day but longer storage periods resulted in discolouration, stickiness and greatly altered nutrient composition. In India investigation showed that postharvest application of lactic acid bacteria such as *Lactobacillus* could inhibit the growth of moulds on straw mushrooms (Gogoi and Baruah 2000).

Summer white button mushroom

Agaricaeae

Agaricus bitorquis. It will freeze at about –1.2 to –0.9 °C (Wright 1942). The cap and stalk are greyish

white and resemble the common mushroom. In Turkey it was found that the average nutritional values (on a dry matter basis) of *Agaricus bisporus*, *A. campestris* and *A. bitorquis* were: crude protein 6.31–8.87%, fat 2.54–3.70% and available carbohydrates 0.18–1.87%. Energy value was 9.59–17.85 kcal 100 g⁻¹. Values of calcium, phosphorus, copper and zinc were 1.64–1.86, 113.78–156.38, 0.52–1.01 and 0.54–1.56 mg 100 g⁻¹, respectively. They concluded that these mushrooms are low in fat, available carbohydrate and available energy but rich in protein and mineral content (Dhar 1992).

Harvesting

Harvesting is when they reach a size that is acceptable to the market, but normally while the velum is still unbroken. For certain markets the sporophore is allowed to open fully with the velum broken, the cap extended and the stalk elongated.

Pretreatments

Pretreatment with 0.25% potassium metabisulphite solution dip had no positive effects and actually resulted in faster loss of quality than in untreated controls (Dhar 1992).

Storage

Pre-cooling for 6 h in a cold room at 4–5 °C increased the shelf life. Storage recommendations included 0–1 °C (Maaker and Merckens 1969). Fresh weight loss during storage at 18 ± 0.5 °C for 5 days was about 10% per day (Smith *et al.* 1993). Stork and Schouten (1978) described three cultivars, Horst K26, Horst K32 and Les Miz K46, which remained white during storage, while those of Les Miz K48 deteriorated in colour and were also the most open.

Controlled atmosphere storage

In trial where *A. edulis* and *A. bisporus* sporophores were held at 18 °C for 5 days in air streams enriched to 5, 10 or 15% CO₂, stalk elongation was markedly less in 15% CO₂. When held in nitrogen streams enriched with 0.25–2.0% O₂, sporophores developed normally

in O₂ at 1% or more, but O₂ levels below 0.5% arrested development (Nichols and Hammond 1976).

Modified atmosphere packaging

Packing in punnets covered with cellophane reduced weight loss without any detrimental effects (Maaker 1971). Storage of the sporophores in non-perforated bags showed better keeping quality than those stored in perforated bags. Of the various packing materials tried polyethylene bags were best for storage of summer white button mushroom. In experiments by Nichols and Hammond (1976) at 18 °C for 5 days non-wrapped mushrooms lost 41% of their original weight and became wrinkled, but the caps remained relatively creamy-white and the stalks elongated only slightly. In contrast, weight loss in overwrapped packs with PVC films (VF 70, VF 71 or RMT 68 H) was no more than 6%, but many of the stalks elongated, split and distorted. Whether overwrapped or not, storage at 2 °C for 6 days resulted in little change in whiteness, and stalk and cap development was retarded compared to storage at 18 °C. Dhar (1992) also found that mushrooms exhibited better shelf life in non-perforated bags, maintaining quality for up to 6 days with little change in colour either at 15 or 20 °C. Dhar also found that sporophores stored in perforated bags began to rot within 4 days. Intense browning, extensive veil opening, increased cap diameter and heavy water condensation were observed in perforated bags at 20 and 25 °C.

Truffles

Tuberaceae

Tuber spp. There are a number of species of truffle including the white truffle *T. magnatum* Pico: Fr or *T. aestivum*, the black truffle *T. melanosporum* Pico, the red truffle *T. rufum* and the summer truffle *T. aestivum* Vitt. The two major species of truffles cultivated in Italy are *T. magnatum* grown principally in medium clay soils and the French périgord truffle *T. melanosporum* grown in drier soils (Massini and Landucci 1988). They grow and reproduce underground in woods, especially beech or oak woods and produce a globular edible fruiting body that can be up to 10 cm

in diameter. *T. melanosporum* is used to make *paté de foie gras*. They are noted for their delicious flavour and the rarer species command very high prices.

Harvesting

Specially trained dogs or pigs are used in the wild to hunt them and dig them up. Truffles harvested at the beginning of the season store better because they have lower water content and are less prone to superficial mould development (Mencarelli 2002b).

Pre-cooling

Only summer truffles or truffles grown in hot areas need pre-cooling because of their higher metabolic rates. Hydrocooling is best and must be done by immersion, which can be part of the washing procedure. After washing excess water should be removed in a well-ventilated room at 4–5 °C. Lowering the temperature helps maintain their characteristic aroma (Mencarelli 2002b).

Postharvest physiology

Respiration rate was given by Mencarelli (2002b) as 20–36 mg CO₂ kg⁻¹ h⁻¹ at 0 °C, 24–45 mg CO₂ kg⁻¹ h⁻¹ at 5 °C and 30–60 mg CO₂ kg⁻¹ h⁻¹ at 10 °C. Truffles produce very low amounts of ethylene and are not sensitive to ethylene exposure (Mencarelli *et al.* 1997).

Storage

Truffles need brushing during washing but excess water must be removed before storage to avoid growth of superficial mould (Mencarelli 2002b). Mencarelli *et al.* (1997) recommended 0 or 5 °C for up to 40 days or 0 °C with 90–95% r.h. for 20–30 days, but care must be exercised in temperature control at 0 °C since freezing will completely destroy their texture (Mencarelli 2002b). Storage life was slightly reduced at 5 °C compared to 0 °C (Mencarelli *et al.* 1997). In *T. melanosporum* two aldehydes (2- and 3-methylbutanal) and two alcohols (2- and 3-methylbutanol) were shown to have a major effect on flavour and during storage at 25 °C all these

compounds were lost by oxidation or evaporation, but at 0 °C a strong amylic fermentation occurred resulting in an increase in their concentrations (Bellesia *et al.* 1998).

Controlled atmosphere storage

When truffles were stored in 1% O₂ and/or 60% CO₂ at 5 and 10 °C ethylene production and weight loss were reduced by the high CO₂ with little effect of the low O₂. Truffles stored in high CO₂ at 5 °C retained firmness, gumminess and chewiness for 35 days similar to those of freshly harvested. The CO₂ treatment at 5 °C kept their strong, typical odour better than samples kept in low O₂ (Mencarelli *et al.* 1997). However Mencarelli (2002b) reported that high CO₂ should be combined with low O₂ to avoid anoxic conditions. Hajjar *et al.* (2010) found that storage in CA of 50% CO₂ + 5% O₂ at 2 °C for 29 days resulted in a reduction in polyphenol contents and antioxidant activity compared to those stored in air. Alcohol dehydrogenase and lactate dehydrogenase activities in CA stored samples decreased together with the related metabolites, ethanol and lactic acid, but after 29 days (final sampling) they increased again, reaching the initial levels but still below the concentrations of those stored in air. Polyamine contents decreased initially in CA samples more than in air-treated truffles but at the final sampling increased significantly (1.5- to 2.3-fold). They concluded that the rapid increase of polyamines and anaerobic metabolism could be an index of the reaction to stress only at the end of storage and the increase in polyamines could provide protection against pathogen attack.

Modified atmosphere packaging

Quality characteristics and aroma were reported to be maintained in low-permeability plastic film packages (Bruno *et al.* 1999, quoted by Mencarelli 2002b).

Velvet shank

Physalacriaceae

Flammulina velutipes (Curt.: Fr.) Sing. also called enokitake and winter mushroom. It is a basidiomycete

gill fungus and at first the cap is conical, but it flattens with age. It is bright yellow or orange in colour often darkening towards the centre when wet and the surface is shiny and sticky and can become undulated with age. The stem is tough, orange brown in colour darkening and velvety towards the base and usually curving upwards. The flesh is yellowish (Chi *et al.* 1998).

Wood blewits

Tricholomataceae

Lepista nuda. It is a gill fungus up to 10 cm in diameter and 10 cm high. The cap is domed and conical as it emerges and gradually flattens and may even become depressed in the centre. It is brown in colour sometimes tinged reddish when young with a smooth surface with a waxy feel and lilac-coloured

flesh. The gills are an intense bluish purple in colour fading to buff as they develop. They have pink spores. The stalk has a bulbous base and tapers slightly and is bluish white sometimes streaked and lined. Its natural habitat is deciduous woods and hedgerows and it tastes delicious. A related species, *L. nebularis*, was found by Vetter (2003) to have a protein content of 39% of its dry weight.

Wood mushroom

Agaricaceae

Agaricus silvaticus. It is closely related to *A. bisporus* and has a brown scaly cap with a stalk that tends to be bulbous towards the base with a distinct ring. It has a mild flavour, but is good to eat although it has a sour smell.

Abbreviations and glossary

% = percent.

µl = mcl = microlitre.

1-MCP = 1-methylcyclopropene is an ethylene inhibitor. Permission has been granted for its use as a postharvest treatment and United States (2002) stated 'This regulation establishes an exemption from the requirement of a tolerance for residues of 1-methylcyclopropene (1-MCP) in or on fruits and vegetables when used as a post harvest plant growth regulator, i.e. for the purpose of inhibiting the effects of ethylene. AgroFresh, Inc. (formerly BioTechnologies for Horticulture) submitted a petition to EPA under the Federal Food, Drug, and Cosmetic Act, as amended by the Food Quality Protection Act of 1996, requesting an exemption from the requirement of a tolerance. This regulation eliminates the need to establish a maximum permissible level for residues of 1-MCP'. The overall conclusion from the evaluation reported on 23 September 2005 by European Commission Health & Consumer Protection Directorate-General was '... that it may be expected that plant protection products containing 1-methylcyclopropene will fulfil the safety requirements laid down in Article 5(1) (a) and (b) of Directive 91/414/EEC' (EC 2005). 'The World Trade Organization does not expect any human health concerns from exposure to residues of 1-MCP when applied or used as directed on

the label and in accordance with good agricultural practices. The data submitted by applicant and reviewed by the Agency support the petition for an exemption from the requirement of a tolerance, for 1-MCP on preharvested fruits and vegetable, when the product is applied or used as directed on the label. This regulation is effective 9 April 2008' (WTO 2008).

a.i. = active ingredient.

ABA = abscisic acid naturally occurs in plants and its production is accentuated by stresses such as water loss and freezing temperatures. It is believed that biosynthesis occurs indirectly through the production of carotenoids. Among its function in plants it inhibits the affect of gibberellins on stimulating *de novo* synthesis of α -amylase. It has some effect on induction and maintenance of dormancy. It induces gene transcription especially for proteinase inhibitors in response to wounding which may explain an apparent role in pathogen defence. It is involved in abscission only in a small number of plants.

ACC = 1-aminocyclopropane 1-carboxylic acid, a precursor of ethylene biosynthesis.

ACC oxidase, an enzyme involved in biosynthesis of ethylene.

ACC synthase, an enzyme involved in biosynthesis of ethylene.

ACC synthesis = 1-aminocyclopropane-1-carboxylic acid, the reaction catalysed by ACC synthase.

ACP = African Caribbean and Pacific countries.

Active packaging is a system that usually involves the inclusion of a desiccant or O₂ absorber within or as part of the packaging material in MAP.

ADP = adenosine diphosphate is a nucleotide made up of adenine, ribose and two phosphate units. It is the product of ATP de-phosphorylation via ATPases to release energy and can be converted to ATP by phosphorylation via ATP synthases to store energy.

AIU = amylase inhibitor.

Anamorph = imperfect state of a fungus when asexual spores may be produced.

APHIS = Animal and Plant Health Inspection Service of the United States.

Appressorium = a thick-walled fungal cell formed from a spore prior to penetration of the plant.

ARS = Agricultural Research Service of the United States.

ATP = adenosine triphosphate is a nucleoside triphosphate used in cells as a coenzyme involved in transport of chemical energy within cells for metabolism.

AVG = aminoethoxyvinylglycine ([S]-*trans*-2-amino-4-(2-aminoethoxy)-3-butenic acid hydrochloride) is an ethylene biosynthesis inhibitor. It is used in apple orchard sprays. Its mode of action is to inhibit the activity of ACC synthase. Another example is that AVG was reported to inhibited wound-induced ethylene production by about 90% in potatoes, but did not affect wound-induced suberisation.

BCE = before currant era, commonly replaces BC = before Christ.

Benomyl (methyl-1-[butylcarbamoyl] benzimidazol-1-yl carbamate) is member of the benzimidazole group of fungicides. Benomyl was made and marketed by Dupont who issued a recall in 1991 due to some of its Benlate 50DF being contaminated with the herbicide atrazine. Dupont eventually paid out some US\$750 million in damages. In 1996 birth defect claims against benomyl were filed, in particular a mother who was exposed to benomyl while

pregnant gave birth to a child who was born without eyes. Dupont was successfully sued for \$4 million. The Environmental Protection Agency in the United States effectively cancelled all other registrants' benomyl product registrations in January 2002. The European Union withdrew authorisation for plant protection products containing benomyl in June 2002. Benomyl is, however, still available.

BTU = British thermal unit.

bu = bushel = a volume of 2200 cubic inches = 36.052 L.

CA = controlled atmosphere.

Ca(NO₃) = calcium nitrate.

CaCl₂ = calcium chloride.

Captafol = *cis-N*-(1, 1,2,2-tetrachloroethylthio)-4-cyclohexene-1,2-dicarboximide. Production for use as a fungicide in the United States was stopped in 1987 and EPA subsequently banned its use on all crops and several other countries have followed suit.

Captan = orthocide = 3a,4,7,7a-tetrahydro-2-[(trichloromethyl)thio]-1H-isoindeole-1,3(2H)-dione, a fungicide.

CAS = controlled atmosphere storage. Increasingly in scientific journals the carbon dioxide (CO₂) and oxygen (O₂) levels in controlled atmosphere stores is expressed as kPa (kilopascals), which is a unit of pressure. Normal atmospheric pressure is 1013.25 millibars and 1 millibar is equivalent to 0.1 kPa. So one atmosphere is 101.325 kPa and 1 kPa is a pressure of approximately 1% of one atmosphere. If one atmosphere was exactly 1000 millibars then 1 kPa would have been exactly 1% of an atmosphere. In terms of percentages levels of CO₂ and O₂ in store are referred to as a *percentage by volume* rather than by mass. For a constituent of a total atmosphere (in this case CO₂ and O₂ as a constituent of atmospheric air) the volume of constituent divided by the volume of total = partial pressure of constituent divided by the pressure of the total. So the volume of a constituent is divided by volume of the total. For 5% CO₂, it would be 5 divided by 101.35 = 4.9% CO₂. In this book in order to simplify the information and provide comparisons between work of different authors all the levels of gases are expressed as % on the basis that 1% = approximately 1 kPa.

CaSO₄ = calcium sulphate.

CAT = catalase.

CE = current era, commonly used for dates as a replacement for AD.

CFM = cubic feet per minute.

CFU = colony forming units.

Chitosan is a natural polysaccharide chemically similar to cellulose with a polycationic nature that is used as an edible coating of fruits. Chitosan forms a semipermeable film and has been used to control postharvest diseases of many fruits such as citrus, grapes, longan, pears, strawberries and tomatoes. For example Wijeratnam *et al.* (2006) successfully used it on pineapples and El Ghaouth *et al.* (1991) as a postharvest coating of cucumbers to reduce water loss and maintain their quality. Nutri-Save is a chitosan-based product.

CIAT = Centro Instituto de Agricultura Tropical at Palmira in Colombia.

CIPC = chloroprophan = 3-chloro-isopropyl-*N*-phenyl carbamate = chloroisopropyl phenylcarbamate, a sprout suppressant.

cm = centimetre.

CMC = carboxy methyl cellulose.

CO₂ = carbon dioxide.

d.w. = dry weight.

Daminozide = Alar = *N*-(dimethylamino) succinamic acid or butanedioic acid mono (2,2-dimethylhydrazide). Daminozide is no longer used on food crops. It was initially registered as a pesticide in the United States in 1963 for use on potted chrysanthemums. The first food use, on apples, was registered in 1968. On fruit trees it affects bud initiation, fruit set, fruit maturation, fruit firmness and colouring, preharvest fruit drop and quality of fruit at harvest and during storage. The US Environmental Protection Agency revoked the tolerances (maximum residue limits) for food uses in March 1990, based on unacceptably high cancer risks to consumers. It is still used on a variety of ornamentals to produce more compact plants. It is absorbed by the leaves and translocated throughout the plant and inhibits internodal elongation (EPA 1993).

DCA = dynamic controlled atmosphere storage. DCA was defined as where the gas mixture will constantly change due to metabolic activity of the respiring fruits or vegetables in the store and leakage of gases through doors and walls. Where the O₂ level falls below a threshold level several metabolic processes will change including ethanol biosynthesis and the chloroplasts will be stressed causing them to fluoresce. DCA uses the measurement of either chlorophyll fluorescence or ethanol production to control the O₂ level in the store.

dicloran = botran = DCNA = 2,6-dichloro-4-nitro-aniline is a fungicide.

DLE = delayed light emission is where fruit is subjected to a bright light and then placed in darkness where a sensor measures the amount of light emitted.

DPA = diphenylamine is an organic compound with the formula (C₆H₅)₂NH. It is used as a preharvest or postharvest scald inhibitor for apples. Its anti-scald activity is the result of its antioxidant properties, which protect the apple skin from the oxidation products of α-farnesene during storage. In the United States the Government approved the postharvest application to apples with maximum residues of 10 µl L⁻¹ for DPA (Hardenburg and Anderson 1962).

DPPH = 1,1-diphenyl-2-picrylhydrazyl.

EC = European Community.

EFE = ethylene forming enzyme = aminocyclopropane 1-carboxylic acid oxidase.

ELISA = enzyme-linked immunosorbent assay is a test that uses antibodies and colour change to identify a substance. It has been used as a diagnostic tool in plant pathology.

EMAP = equilibrium-modified atmosphere packaging is where the internal concentration of the gases within packages could be predicted by applying an integrated mathematical model and using highly permeable packaging films.

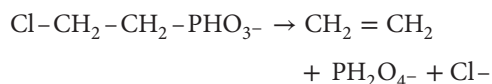
EPA = Environmental Protection Agency in the United States.

Etacelasil = 2-chloroethyl-tris-[ethoxymethoxy] silane.

Ethoxyquin = (1,2-dihydro-2,2,4-trimethylquinoline-6-yl ether). In the United States the Government approved the postharvest application to apples with maximum residues of $3 \mu\text{L L}^{-1}$ for Ethoxyquin (Hardenburg and Anderson 1962).

Ethylene is a hormone produced by plants that can affect various processes including respiration rate and initiation of ripening in climacteric fruit. Ethylene in a store has been traditionally referred to as *parts per million (ppm)*, which is based on mass for mass or volume for volume. It has become more conventional to express these terms as microlitres per litre and abbreviated as $\mu\text{L L}^{-1}$. They are the same so that $100 \mu\text{L L}^{-1}$ ethylene is the same as 100 ppm of ethylene.

Ethrel = ethephon = 2-chloroethyl phosphonic acid. It breaks down in the presence of a base to produce ethylene as follows:



EU = European Union.

f.w. = fresh weight.

FDA = Food and Drug Administration of the United States.

Folpet = (*N*-[(trichloromethyl)thio] phthalimide) is a broad-spectrum contact protectant fungicide, which acts by denaturing fungal proteins when it reacts with their thiol groups.

GA = gibberellins are named GA_1 to GA_n in order of discovery and there are about 136 gibberellins identified from plants, fungi and bacteria. They are classified on the basis of structure and function. Among the physiological processes stimulated by gibberellins are parthenocarpic fruit development and delayed senescence in leaves and citrus fruits. GA_3 = gibberellic acid was the first gibberellin to be structurally characterised.

GA_3 = gibberellic acid.

GC = gas chromatography.

h = hour.

HPLC = high-performance liquid chromatography is a technique used to separate a mixture of compounds in analytical chemistry with the purpose of identifying, quantifying or purifying the individual components of the mixture.

Humidity is the amount of atmospheric moisture in a store and is expressed at relative humidity or % r.h. It may be defined as the ratio of actual water vapour pressure in air to the maximum possible water vapour pressure at the existing temperature, that is the amount of water vapour relative to saturation (100% r.h.) at that temperature. It can also be expressed as vapour pressure deficit (VPD). VPD is the difference between the saturation vapour pressure and the actual vapour pressure at the existing temperature. VPD can be expressed in millibars (mb) or millimetres of mercury (mm Hg) for example:

Temperature ($^{\circ}\text{C}$)	VPD (mm Hg)	Approximate (% r.h.)
12	3.8	60
12	2.7	80
12	0.6	94
6.5	0.4	94

Hydrothode = an opening in the margin of some leaves where water can be discharged.

Hypobaric storage or low-pressure storage has been used for several decades as a way of affecting the partial pressure of O_2 in fruit and vegetable stores. Pressure is referred to as *millimetres of mercury* or *mm Hg* where atmospheric pressure at sea level is 760 mm Hg. This can also be referred to a 1 atm. and reduced pressures as a fraction of atmosphere or of normal pressure, e.g. $\frac{1}{3}$ atm. = 253 mm Hg.

IAA = indole acetic acid is a plant growth substance sometimes called auxin. Charles Darwin discovered plant growth substances as an outcome of his investigation of phototropic effects of cereal coleoptiles in 1897. IAA was described as a plant growth substance by F. Kogl and his associates in 1934. IAA is synthesised at growing points of plants. Several synthetic auxins have been produced and used in plant science including IBA (indole butyric acid), NAA (naphthalene acetic acid), 2,4-D (2,4 dichlorophenoxy

acetic acid) and 2,4,5-T (2,4,5 trichlorophenoxy acetic acid).

imazalil = 1-[allyloxy-2,4-dichlorophenethyl] imidazole, is a fungicide.

IPC = propham = IPPC = isopropyl-*N*-phenyl carbamate, a sprout suppressant.

J = joules.

kg = kilogram.

kgf = kilograms force, which measures the resistance to the penetration of a pressure tester into a fruit or vegetable as an indication of its firmness.

Koch's postulate is used to determine the cause of a disease. The pathogen is isolated from the diseased area of the plant; it is then cultured. When it is clear that the culture in pure the organism is inoculated into a healthy plant of the same species and cultivar. If the same disease symptoms are observed and the pathogen isolated is the same as the culture then it can be described as causing the symptoms.

L = litre. 1 litre = 1000 ml (millilitres) = 1,000,000 μ l (microlitres) = 1,000,000,000 nl (nanolitres) = 1,000,000 ppm (parts per million) = 1,000,000,000 ppb (parts per billion).

lb = avoirdupois pound, 1 lb = 0.4536 kg = 453.6 g.

M = metre.

MA = modified atmosphere.

Maneb = ethylene bisdithiocarbamates group broad-spectrum, protectant fungicide is a multi-site inhibitor in dithiocarbamate (M3) group of fungicides. Other members of this fungicide group include mancozeb, ferbam, metiram, thiram and ziram. Because of health concerns surrounding dithiocarbamate fungicides and associated metabolites the number of labelled use crops has declined and use restrictions have increased over the years.

MAP = modified atmosphere packaging.

Maximum residue level = maximum residue limit (MRL). They are used for agricultural chemicals and are legal provisions by such organisations as WHO (World Health Organisation) and the JMPR (Joint Meeting on Pesticide Residues). Most countries also

have their own MRL, e.g. the EPA (Environmental Protection Agency in the United States). The EU provides MRL and these are communicated in directives issued in the Official Journal of the European Communities. For example Council Directive 93/58/EEC of 29 June 1993.

mcg = μ g = microgram.

MENA = methyl ester of naphthalene acetic acid.

Methyl jasmonate (MeJA) is a fragrant volatile compound initially identified in flowers of *Jasminum grandiflorum* and was subsequently found to be distributed ubiquitously in the plant kingdom. It is a volatile organic compound used in plant defence and many diverse developmental pathways including fruit ripening and senescence. Plants produce jasmonic acid and methyl jasmonate in response to many biotic and abiotic stresses, which build up in the damaged parts of the plant. It can induce the plant to produce multiple different types of defence chemicals including photoalexins. MeJA induces ethylene-forming enzyme activity, which increases the amount of ethylene to the amount necessary for fruit maturation. Increased amounts of methyl jasmonate in plant roots have shown to inhibit their growth. Cheong and Choi (2003) used functional genomics and bioinformatics to identify many MeJA responsive genes and provide insights into how plants use volatile signals to withstand diverse and variable environments.

MH = maleic hydrazide was first synthesised in 1895 but its ability to regulate plant growth was not discovered until 1949 and it was first registered as a plant growth regulator in 1952. In early works the inhibitory effects of MH on plant growth were mainly considered to result from inhibition of enzymatic activity and interference with plant growth regulators. Subsequently it was shown that MH acts as an inhibitor of the synthesis of nucleic acids and proteins. Among higher plants selective sensitivity to the toxic effects of MH is well-proved. This phenomenon seems to be due to the differential ability of various plant species to detoxify the chemical. Plants can break down MH into several products, one of which, hydrazine, is a mutagen and carcinogen in mice and rats. MH does not seem to be toxic to bacteria and fungi and is degraded by soil microflora

(Swietlińska and Zuk 1978). They also expressed concern about potential carcinogenic effects but the potassium salt was not found to be carcinogenic and has been classified as not considered to be a human carcinogen. In concluding the Rebuttable Presumption Against Registration in June 1982 EPA allowed continued use of maleic hydrazide and its potassium salt, but established an upper limit of 15 ppm for the contaminant hydrazine (associated with tumour induction) in technical-grade maleic hydrazide. At this level lifetime cancer risks for both dietary and worker exposure are not of concern. In the United States application is prohibited within 7 days of harvest (Anonymous 1994).

mm Hg = millimetres of mercury, which is a measure of pressure.

ml = millilitre.

mmol = millimole.

Mole is the amount of a substance that corresponds to its formula mass in milligrams and a millimole (mmol) is a unit of metric measurement that is equal to one thousandth (10^{-3}) of a mole.

MRL = maximum residue level.

MS = mass spectrometer.

Mycotoxins = poisonous substances produced by some fungi.

N = Newton.

N₂ = nitrogen.

NIR = near infrared reflectance. Optical properties of fruit and vegetables can be measured by various methods including in the near infrared spectrum range of 800-1100 nm that has shown good correlation with texture in crops including apples and asparagus.

NAA = naphthaleneacetic acid

NaOCl = sodium hypochlorite.

O₂ = oxygen.

OECD = Organisation de Coopération et de Développement Économiques, Paris

OTR = oxygen transmission rate.

Oz = avoirdupois ounce, 1 oz = 28.35 g.

PAL = phenylalanine ammonia lyase.

PG = polygalacturonase.

Plastic films are used for packing fruit and vegetables, usually to modified atmosphere around them, and the abbreviations used are as follows:

BOPP	bi-oriented polypropylene
EVAL	ethylene vinyl acetate copolymers
EVOH	ethylene vinyl alcohol copolymers
HDPE	high-density polyethylene
I	ionomer
LLDPE	linear low-density polyethylene
LDPE	low-density polyethylene
MDPE	medium-density polyethylene
OPP	oriented polypropylene
PB	polybutylene
PE	polyethylene
PET	polyethylene terephthalate
PPP	polymethyl pentene polymeric
PP	polypropylene
PO	polyolefin
PS	polystyrene
PVB	polyvinyl butyral
PVC	polyvinyl chloride
PVDC	polyvinylidene chloride

Plastic films are used in postharvest technology of fruits and vegetables, but their thickness is expressed in different units. The approximate relationships between the units used to describe the thickness of plastic films are given as follows:

Gauge	Inches	mm	Microns (μm)
4	= 0.00004	= 0.00100	= 1
48	= 0.00048	= 0.01200	= 12
50	= 0.00050	= 0.01250	= 12.5
75	= 0.00075	= 0.01875	= 18.75
100	= 0.00100	= 0.02500	= 25
125	= 0.00125	= 0.03125	= 31.25
150	= 0.00150	= 0.03750	= 37.5
160	= 0.00160	= 0.04000	= 40
180	= 0.00180	= 0.04500	= 45
200	= 0.00200	= 0.05000	= 50
300	= 0.00300	= 0.07500	= 75
400	= 0.00400	= 0.10000	= 100
500	= 0.00500	= 0.12500	= 125

PME = pectin methylesterase.

POD = pyrogallol peroxidase.

ppb = parts per billion.

ppm = parts per million, 1 ppm = 1 $\mu\text{l L}^{-1}$.

PPO = polyphenol oxidase.

pVACs = provitamin A carotenoids.

Quailing is where citrus fruit are too turgid at harvest, the oil glands in the skin can be ruptured releasing phenolic compounds and causing damage to the peel resulting in oleocellosis (Wardlaw 1937). In some cases fruit were kept in the basket in which they were harvested for a couple of hours before being transported to the packhouse. This allowed the fruit to lose a little moisture, a practice that is called quailing.

r.h. = relative humidity is the amount of moisture vapour air can hold compared to the maximum, or saturation, multiplied by 100 to give a percentage.

RAE = retinol activity equivalent, where 1 μg of RAE is equivalent to 1 μg of all-*trans*-retinol, 12 μg of all-*trans*- β -carotene, or 24 μg of other provitamin A carotenoids.

Respiration rate is given in various forms. To calculate $\text{ml kg}^{-1} \text{h}^{-1}$ from $\text{mg kg}^{-1} \text{h}^{-1}$ divide the rate by 2 at 0 °C, 1.9 at 10 °C and 1.8 at 20 °C. To calculate heat production, multiply $\text{mg kg}^{-1} \text{h}^{-1}$ by 220 to get British thermal units per tonne per day or by 61 to calculate kcal per tonne per day. Watts per tonne is also used for respiration rate, where $1 \text{ W t}^{-1} = 20.4 \text{ kcal tonne}^{-1} \text{ day}^{-1} = 82.1 \text{ Btu tonne day}^{-1} = 73.3 \text{ Btu } 2000 \text{ lbs}^{-1} \text{ day} = 0.167 \text{ ml CO}_2 \text{ kg}^{-1} \text{ h}^{-1} = 7.0 \mu\text{mol CO}_2 \text{ kg}^{-1} \text{ h}^{-1} = 0.308 \text{ mg CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$.

RQ = respiratory quotient is the ratio of the amount of CO_2 produced to the amount of O_2 consumed during respiration.

SAM = S-adenosyl methionine, a precursor during ethylene biosynthesis in plants.

Semperfresh = a commercially available coating based on sucrose esters of fatty acids and sodium carboxymethyl cellulose, which had been shown to reduce the gaseous exchange between fruits and the outside air.

SO_2 = sulphur dioxide.

SOD = superoxide dismutase.

Spore = the reproductive part of a fungus.

Sta-Fresh is a protective postharvest coating layer for use on some fruits, e.g. Hu *et al.* (2011) on pineapples and sweet passion fruit but mainly in apples in United States. It is claimed to retard moisture loss, slow respiration rate and provide a protective barrier that seals tiny scratches and helps prevent infection by microorganisms. It can be applied by a spray-brush-type applicator at the rate of 1 L per 1000 kg of fruit although other concentrations have been used.

TA = total acidity = titratable acidity.

TBZ = thiabendazole = 2-thiazol-4-yl benzimidazole, is member of the benzimidazole group of fungicides.

TCNB = tecnazene = Fuserex = 2,3,5,6-tetrachloro-nitrobenzene, a fungicide and sprout suppressant.

TEAC = Trolox equivalent antioxidant capacity measures the antioxidant capacity of a substance, as compared to the standard.

Teleomorph = perfect or sexual state of a fungus.

thiophanate methyl = 1,2-di-[3-methoxycarbonyl-2-thioureido] benzene, a fungicide.

TIU = trypsin inhibitor.

ton = 2240 pounds = 1016 kg.

tonne = 1000 kg.

TSS = total soluble solids; sometimes abbreviated as SSC.

Ultraviolet radiation uses ultraviolet (UV) light, is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, that is in the range 10–400 nm. UV has been used as a treatment on postharvest of fruit and vegetables with UVC being generally the most effective.

	Wavelength range (nm)	Energy per photon (eV)
Ultraviolet A = UV-A	400–315	3.10–3.94
Ultraviolet B = UV-B	315–280	3.94–4.43
Ultraviolet C = UV-C	280–100	4.43–12.4

USDA = United States Department of Agriculture.

USDA Nutrient Database (USDA 2012a) files contain mean nutrient values per 100 g of the edible portion of food, data associated with calculated values. Protein values were calculated from the amount of total nitrogen in the food. The analytical methods used to determine the nitrogen content of foods are AOAC 968.06 (4.2.04), 992.15 (39.1.16) and 990.03 (combustion); and 991.20 (Kjeldahl) (AOAC 2010). The specific factor applied to each food item is provided in the N factor field with the general factor of 6.25 being used to calculate protein in items that do not have a specific factor. The adjusted protein conversion factors used to calculate protein for mushrooms was 4.38. Carbohydrate was determined as the difference between 100 and the sum of the percentages of water, protein, total lipid, ash and, when present, alcohol.

Total carbohydrate values include total dietary fibre. Food energy is expressed in kilocalories (kcal) and kilojoules (kJ). One kcal = 4.184 kJ. Vitamin A is also reported in international units (IU). One IU is equivalent to 0.3 µg retinol, 0.6 µg β-carotene or 1.2 µg other provitamin A carotenoids and thus overestimates bioavailability.

VPD = vapour pressure deficit = the deficit of the pressure of a vapour in contact with its liquid or solid form and may be measured in mm mercury.

Watts tonne⁻¹, a measure of respiration rate where 1 watt tonne⁻¹ = 0.308 mg CO₂ kg⁻¹ h⁻¹.

WTO = World Trade Organisation.

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Figure 4 Ackee fruit ready for harvesting where the fruit has split and the seeds are exposed.



Figure 11 Small seedless avocados alongside a conventional avocado. (Photo: Fernando Cosman.)



Figure 13 Bitter gourd on sale in a supermarket in Los Angeles in the United States.



Figure 14 Breadfruit on sale in an open market in Bedford in the United Kingdom in July 2009.



Figure 18 Gobo on sale in California in the United States.



Figure 21 Cassava on sale in a Californian supermarket with waxed cassava from Costa Rica (left) and Chinese yucca (right).



Figure 23 Waxed cassava on arrival in Britain after sea-freight transport from Costa Rica in July 2009.



Figure 26 Celeriac on sale at a UK green grocer's shop in 2013.



Figure 29 Nagaimo on sale in a California supermarket in 2008.



Figure 32 Lobok on sale in a Californian supermarket in 2008.



Figure 33 Packing garlic for export in Mexico.



Figure 36 Kohl Rabi on sale in a green grocer's shop in the United Kingdom in 2013.



Figure 38 Chinese arrowroot on sale in a Californian supermarket in November 2008.



Figure 39 Water lily on sale in a Californian supermarket in November 2008.



Figure 40 Okra from Jordan on sale in an open market in Bedford in Britain in July 2009.



Figure 46 Papa criolla in woven polypropylene sacks on the wholesale market in Bogotá in Colombia.



Figure 55 Eddoes for sale in Huddersfield in the United Kingdom.



Figure 69 Jicama on sale in a supermarket in California, USA.

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